UNIVERSITY OF DERBY

Competition and collaboration in the extractive industries in a world of resource scarcity using a Game theory approach

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Table of contents

Figures

Tables

Preface

I, Shahla Seifi Crowther, hereby declare that I am the author of this thesis entitled Competition and collaboration in the extractive industries in a world of resource scarcity using a Game theory approach. It contains no material that has been submitted or accepted previously for any academic degree.

Shahla Seifi Crowther

Abstract

Sustainability has become one of the most important issues for businesses, governments and society at large. Increasingly, it features in all planning for future activity. The topic is under much debate as to what it actually is and how it can be achieved, but it is completely certain that the resources of the planet are fixed in quantity, and once used, cannot be reused except through being reused in one form or another. This is particularly true of the mineral resources of the planet. These are finite in quantity, and once fully extracted, extra quantities are no longer available for future use. In this thesis, it is argued that the remaining mineral resources are diminishing significantly and heading towards extinction. Once mined and consumed, they are no longer available for future use other than what can be recycled and reused. What is becoming important therefore – both for the present and for future sustainability – is not the extraction of minerals, but their distribution. Future scarcity means that best use must be made of what exists, as sustainability depends upon this, and best use is defined in this thesis as utility rather than economic value, and this must be considered at a global level rather than a national level. This thesis investigates the alternative methods of achieving the global distribution of these mineral resources and proposes an optimum solution.

It does so by showing the efficacy of Game theory for such strategic decision-making, and by developing the theory with some extensions pertinent to the environment being described, before performing the necessary mathematical manipulations to evaluate this environment, and then applying this to real world data. The findings are supported by using linear programming and sensitivity analysis, and by using real world data. Application of the results obtained would raise a number of problems with market regulations and with the geopolitical situation, and these also are explored at length.

In achieving this research, the main contribution of this thesis is through identifying the new environment and the extending of Game theory into this environment and in developing the necessary extensions. Previous research has only proposed methods to deal with this, but never actually developed and tested any model; therefore, this model itself, is a contribution. An additional contribution has been made through the application of those extensions into the practical global arena, and in the consideration of the role of regulation in the management of the market for resources in a way which is effective globally rather than locally. Essentially, this is through an understanding of the dichotomy between competition and collaboration,

where this thesis argues that the conventional economic mode does not work to best results. Therefore, this thesis adds to the discourse through the understanding of the importance of the depletion and finiteness of raw materials and their use for the present and the future, in order to achieve and maintain sustainability.

Glossary of Game Theory Terminology

Dominance

This occurs when one strategy is always better than any other strategy

Nash equilibrium

A stable situation in which no player can improve their outcome by a change of strategy, if the other players make no change to their strategy

Pareto optimality

This exists where there is no alternative outcome which makes at least one player better off, with the other no worse off.

Prisoners' dilemma

A paradoxical situation in which two individuals, acting in their own self-interests, do not produce the optimal outcome. It shows why two completely rational individuals might not cooperate, even if it appears that it is in their best interests to do so.

Chapter 1

Introduction to Research

1.1 Introduction to topic

In 2019, Earth Overshoot Day occurred on 29 July, 2 days earlier than in 2018, 3 days earlier than in 2017 and 25 days earlier than five years previously in 2014. Earth Overshoot Day is measured by the Global Footprint Network[1] and is the day when humanity has exhausted the total natural resources of the planet for the year. For the rest of the year, society operates in an effectively overdrawn mode and in ecological overshoot, by making use of, and depleting, local resource stocks, and accumulating carbon dioxide in the atmosphere. This overshoot first occurred in 1987, and the day in which it occurs has become earlier with each succeeding year. The concept is based on the work of Wackernagel et al. (2002).

It is generally assumed that the scarce resources of the world are the natural (i.e. biological) resources, which can be reproduced through growth. Equally, however, we can be absolutely certain that all the resources of the planet are finite and must ultimately be a limiting factor to growth and development. The resources available to people are heavily used – and so, Earth Overshoot Day gets earlier each year, and clearly, this is not sustainable. Although this refers to the biological resources of the planet, which are effectively renewable through growth from one year to the next, it is equally certain that the mineral resources of the world are finite in quantity, and that these cannot be renewed.

It is a statement of fact that once these mineral resources are used, they are not available for future use and, despite the basis of economics assuming so, one resource can never completely substitute for another (Bretschger & Smulders, 2012). Consider, for example, Easter Island: once the trees had been fully used, then no resource was available as a substitute (Pakandam, 2009), and such activities as sailing had to be terminated alongside the termination of the construction of the famous statues. The lack of sufficient resources of raw materials to maintain current production, let alone to provide for sustainable development as outlined by Brundtland

[1] www.footprintnetwork.org

(WCED, 1987), has become known as resource depletion (West, 2011), and is one of the problems which the inhabitants of the planet must currently face and address.

The organisation of the economic system which is currently operating within the world is determined by an assumption that development is both possible and desirable, and that markets and the pricing system act as mediation for the acquisition of the additional resources required for that development. This is perfectly matched to the assumptions made by Brundtland (WCED, 1987), and accepted unquestioningly ever since. Price has been accepted as the medium of exchange within the market system (Richardson, 1995), and the free market has become dominant. As a consequence of this acceptance, the focus of governmental attention has been upon the operation of the pricing system, with a desire to reduce transaction costs, and agreeing and implementing the various rounds of GATT[2] / WTO[3], as the means for reducing the transaction costs of international trading. At the same time, environmentalists (e.g. Ciriacy-Wantrup & Bishop, 1975; Monfreda, Wackernagel & Deumling, 2004) have been arguing that the resources of the world are overused, and that this usage is not sustainable at this level; consequently, there is a general acceptance of the meaning of resource depletion (Prior et al., 2012).

This has been a focus of concern for people in the western (and therefore developed) world, often with an assumption that technological development will alleviate the problem (Kamien & Schwartz, 1978; Dasgupta & Stiglitz, 1981). Elsewhere, a number of countries have adopted a strategy of rapid growth and economic development (Mahadevan & Asafu-Adjaye, 2007). Principal among these have been the BRIC countries[4]. These countries have access to a large proportion of the remaining natural resources of the world, while also having large populations, and therefore great scope for rapid economic growth (see, for example, Agrawal, 2015). Therefore, this development affects the world economic system, and has the effect of increasing demand for raw materials (in the context of this thesis, this is equated to minerals) and so, of bidding up the cost of resources and placing a limitation upon the possibility of development by increasing the cost of economic activity. This, in turn, places tension into the world economic system in a way which will become more pronounced as development continues, and resource depletion, with the consequent shortages, becomes more apparent.

[2]General Agreement on Trade and Tariffs
[3]World Trade Organization – the successor to GATT
[4]Brazil, Russia, India and China.

However, under this model of the market, demand for raw materials in the production process will continue to rise, as consumption (and its corollary production) continues to increase without any increase in available supply of these raw materials (see section 2.2 for details). This is also a factor of concern for the energy requirements of the world.

Thus, there are changes happening in the world, and arguably, it is entering an era in which, dealing with the consequences of climate change, environmental problems, and resource depletion are becoming significant (Hook & Tang, 2013; Swart Robinson & Cohen, 2013). As a consequence, there are a number of issues which have become more important for manufacturing companies. One issue is that there is a general recognition that resource depletion is taking place (Northey, Mudd & Werner, 2018). In effect, this means that resources are not just fully utilised, but also used to such an extent that they become in short supply in the future (Vincent, Panayotou & Hartwick, 1997). A lack of resources inevitably leads to increasing scarcity, and therefore, increases the transaction cost of their acquisition. It does so, both because they become scarcer and difficult to acquire from more remote sources, but also because competition for these limited quantities increases between the various firms which need to acquire them. Another issue affecting these companies is that of managing in a post-Hubbert's Peak world (Kerr, 1998), which requires ever more efficient use of energy. Naturally, efficient operations reduce the cost of manufacture, and this is an important factor in the development of sustainability (Waeyenbergh & Pintelon, 2002). It also implies the need for the most efficient use of the limited resources of raw materials to maximize their productive use. In order to address this problem, a holistic approach is required, which maximises benefit to the world as a whole. Of particular concern for this thesis is the best way to manage production and distribution of minerals to achieve a sustainable economy for the world. Addressing this issue is the focus of this thesis.

The issue of sustainability has come to prominence currently (Kates et al., 2001) – not just in the business and academic worlds, but also in the media and popular opinion (Lubin & Esty, 2010). Indeed, it often seems that everyone is concerned with sustainability. At the same time, there has arisen a general recognition of the problems ensuing from resources depletion (Prior et al., 2012). At present, it is common for a person to be able to talk knowledgeably about their carbon footprint (Wiedman & Minx, 2007), and most businesses are making statements about sustainability and that they are taking steps to achieve carbon neutrality (Weideman et al., 2008). This will be returned to and developed more fully in the succeeding chapters.

This attention has led to sustainability becoming important at all levels (societal, local, personal, business) (Hart, 1997). Sustainability is, of course, a controversial issue, and there are many definitions of what is meant by the term (Glavic & Lukman, 2007) and how it becomes manifest (Marrewijk & Were, 2003). A general approach to the problem is that sustainability is concerned with the use of environmental resources (Moldan, Janouskova & Hak, 2012). Thus, it has been assumed that addressing the straightforward issues will ensure that the problem has been addressed (Yanarella & Levine, 2008). This makes good press and is comfortable, but implies that society must use no more of a resource than can be regenerated. This can be defined in terms of the carrying capacity of the ecosystem (Arrow et al., 1995), and described with input – output models of resource consumption. However, it does not deal with mineral depletion.

One factor to be explored in this thesis is that there is synergetic relationship between distribution of increasingly scarce mineral resources and sustainability, as many of the issues are shared. It should also be apparent that the minimisation of the use of resources is central to sustainability – of both mineral resources and financial resources. Later, it will be argued that financial resources are less important than scarce environmental resources, and therefore, that the basic economic model of the market is no longer correct.

1.2 Problem statement

It is accepted that the mineral resources of the planet are finite; consequently, this is a factor which will create a limit to growth and development, and which is, therefore significant for this thesis. Not only are they finite, but they are considered to be depleted; arguably, this is one of the factors which has helped to create the current interest in sustainability. This is particularly important for the extractive industries and many commodities such as tin or aluminium have become scarcer and in short supply, as will be discussed in chapter 2. So too are many of the minerals required for the electronics industry. As an example, the tin in Malaysia which led to the foundation of Kuala Lumpur (KL), the major city in the country, is now fully extracted there, which has led to recycling has become an important aspect of the industry. Kuala Lumpur was founded for this tin, because the tin in the UK had already been fully extracted; Ampang was the principle area for tin mining. So, KLCC has always been at the centre of KL life and the Petronas twin towers stand in this area. Petronas is the principle oil extraction company in Malaysia, and so, the extinct tin has been replaced by oil and gas as

the fuel for KL development, but this too is ending as it becomes fully extracted. With the exhaustion of minerals in any particular area, the thriving industries based around this have also gone, and alternative sources of supply were needed – preferably from within the extensive British Empire. This was a part of the British, and other Western (primarily European) countries, seeking further development, and therefore, beginning to exploit the resources of other parts of the world for economic reasons, rather than for the spoils of conquest. Similarly, and on a continuing basis, other environmental resources – metals and minerals – are becoming fully extracted, and consequently, the companies based upon them disappear, as do the jobs in those industries. This is an obvious source of concern for people, and has led to the current president of the USA, Trump, taking actions to try to prevent this for coal mining (Financial Times, 19 June 2019)[5].

Conversely, in Derbyshire the galena ore, from which lead is extracted, has been used for the last 3500 years and is worked out (Shirley & Horsfield, 1944). However, the waste from that mining is still used and reworked, along with some of the mines, in order to extract fluorspar (Bramley, 1991) and barite - minerals which were of no use during the mining of galena, but are now important for modern industrial production processes. So, previously discarded resources can subsequently become valuable.

Nevertheless, one resource is of particular concern, and this is oil, because much economic activity is enabled by the energy created through the use of oil. Arguably, at the present time, Hubbert's Peak has arrived, and supply will not increase to meet increasing demand. For some, the wars and instability in the Middle East, particularly the problems in Iraq and Iran have been caused by oil shortage rather than by any concern for political or religious issues. Hubbert's Peak (Deffeyes & Silverman, 2004) is now commonly known about and currently a debate is taking place as to whether or not peak oil production has arrived. Arguably, it has been reached in parts of the world such as the North Sea, but it is less certain if it has been reached for the world as a whole. Indeed, the discovery of oil shale, particularly in Northern America, has changed the debate, and there is less urgency in finding alternatives, as Hubbert's peak has been delayed for a time. Unfortunately, this extension is likely to be short-term and last for, perhaps, 25 years (Jones, Hillier & Comfort, 2015), and so, the issue of sustainability has merely been delayed, rather that eliminated. Sustainability – and sustainable development –

[5] Financial Times https://www.ft.com/content/0da01384-92b0-11e9-aea1-2b1d33ac3271 accessed 2/12/2019

and its current prominence is based upon the need for energy, and there are still insufficient alternative sources of energy. Resource depletion, and particularly energy resource depletion, is probably the most significant cause of the current widespread interest in sustainability. The subject matter of this thesis is that of dealing with this lack of resources. In the context of this thesis, these resources are defined as all the extractive resources of the planet no matter where located.

Game theory was developed initially during the immediate post war period, and was quickly seen to be able to assist governments – and particularly their diplomatic and military agents – in strategic decision-making (e.g. Schwenk, 1995; Blokhuis et al., 2012 and see section 2.14). It has been found to be suitable and effective for strategic decision-making. Later, it has also been adopted by businesses as a strategic decision-making tool, because it is able to take into account the possible responses of their competitors. It has proved equally effective as an application in the business arena (e.g. Saloner, 1991; Camerer, 1997 and see section 2.16). It has since been widely used in a number of other areas, such as environmental analysis or social anthropology, where required outcomes are not clear and certain. All of these factors make it possible to see how to utilise Game theory to investigate sustainable materials consumption, which is the subject matter of this research. Indeed, it will be demonstrated in this thesis that Game theory is an appropriate and suitable application to investigate this problem.

On this basis, therefore, the problem statement can be defined as follows:

Resource depletion is manifest in many ways, but principally concerning the extraction of minerals and energy production and consumption. Economic activity in this new environment needs to be defined and explained to enable and assure sustainability. This thesis uses Game theory to provide a mechanism in order to achieve this.

1.3 Aims and Objectives of the thesis

The focus of this thesis is to investigate the best way to distribute the available mineral resources to be used in the manufacture of products and services. It is not disputed that the available mineral resources of the world are fixed in quantity, although they can be extracted and used at varying speeds. Speedy use just means that all available will be used sooner, and it is noted that there is some disagreement concerning the speed of exhaustion, as will be

discussed in chapter 2. Essentially, for sustainability (at a global level), this distribution needs to achieve an acceptable degree of equity between individuals and between nations; the alternative would probably be conflict, which would not lead to sustainability.

Two alternative methods of distribution are considered. One is through the market with prices being set by supply and demand. Given a recognition of an environment in which resources are depleted, as resources become scarcer, there is an increasing need to bid for them, thereby increasing the competition between firms. It is argued that this is a new situation for the market economy of the world, and that this has not currently been recognised; it is new, because supply is not expandable when there is no more to be had and so demand becomes the only variable, with use value becoming more significant than price. Effectively, this would mean, therefore that the richest would be able to acquire all the available resources. The alternative, which is considered here, is a cooperative approach based upon a form of governance and regulation to address its working, rather than simple pricing. This new environment requires a different approach, and the argument in this thesis is developed to deal with this situation. The aims of this thesis, therefore are:

- To identify and describe this new environment
- To understand the optimum operation of the market in such an environment
- To consider the problems arising therefrom.

In this context, optimum is defined as facilitating sustainability in the most effective manner.

The approach taken is to look at Game theory as a method for describing the environment and its alternatives and the resultant implications. From this, the necessary calculations are undertaken and the optimum course of action identified. The effects are calculated first theoretically, and subsequently empirically, and the implications considered.
Thus, the objectives have been set as follows:

1. To consider and define the requisite mineral extraction in this new environment, and to consider the implications for sustainability.
2. To consider the alternative methods of distribution (labelled competition and cooperation in this thesis) of those minerals, and the effect upon recipients.

3. To develop the necessary extension to Game theory which will deal with resource depletion, and to perform the necessary theoretical developments for this environment.
4. To apply the resulting formulae in the empirical calculation of the effects of resource depletion.
5. To identify and consider the requirements for governance in the management of the new distribution environment and the implications of this.

1.4 Research questions

According to ISO 26000, there are seven principles that companies should abide by as follows: accountability, transparency, ethical behaviour, respect for stakeholder interests, respect for the rule of law, respect for international norms of behaviour, respect for human rights. Here, we can see that an enterprise is deemed to be more responsible than before. Their responsibility extends beyond simply improving profitability. But as it was pointed out during the ISO General Assembly in 2008, the existing international standards have not yet paid enough attention to sustainable development. This fact is obviously noticed in the field of energy consumption. Lack of universally recognized energy labelling standards is a hindrance for sustainable development, as it prevents consumers from making the most sustainable decisions.

As mineral resources become scarcer through depletion, their distribution to parties who will use them becomes more crucial. This is true, whatever method of extraction is employed and whatever technological developments take place for either extraction of the mineral or for use of the mineral itself. This is considered in detail primarily in chapter 2. What becomes of prime importance is the need to ensure that the use of the available minerals is optimised, and the method of distributing these is paramount to this.

The approach taken in this thesis, therefore is to address the problem through the following research questions:

1. Does resource depletion have an impact upon the way firms acquire the resources for their production, and if so, then how?
2. What changes are needed to address the issue of depletion for sustainability in the global market?

3. Would a new approach to the global management of distribution of planetary resources be beneficial?
4. What kind of interventions, if any, are needed for effective management of the resources of the planet?

1.5 Contribution to knowledge

This thesis contributes to knowledge in the area of sustainability and its relationship to mineral extraction and distribution in a global context. This is in two main areas. Firstly, this is a new application of Game theory which has never been used in this area; moreover, it is developed by the creation of some extensions which are needed to strategise in an era of depleting resources. Secondly, it makes a contribution in the area of mineral resource management and distribution and its relation to global sustainability. Broadly speaking, this is in the disciplinary area of strategy formulation and resources management with extensions into a range of other areas. Because this is a broad area and affects both businesses and countries themselves, there are policy implications from this argument. Thus, the contribution is both through the creation of theory and through its application in a new area. This is explained and developed in subsequent chapters before revisiting in chapter 7.

1.6 Structure of the thesis

The rest of the thesis explains these questions more fully and develops answers to them. In doing this, the argument is developed which makes use of mathematical analysis, principally through the use of Game theory, but supported by linear programming. In order to do so, some new extensions to Game theory are required, and the main contribution of this thesis is through the extending of Game theory into this new environment, and also in developing those extensions. The contribution of the thesis is further made by the application of those extensions at a practical level in the global arena. Additionally, this thesis extends to consider the role of regulation in the mediation of the global market for resources which must be treated in a global manner. In order to do so, an understanding of the dichotomy between competition and collaboration is necessary and undertaken, and the thesis shows that the conventional economic mode of the market is flawed in such an environment.

The remainder of the thesis is structured as follows:

The next chapter (Chapter 2) provides a literature review of the relevant strategy, economic and sustainability theory within the area of resource extraction and distribution, with necessary market implications. This establishes the gap which is to be filled by this research, and situates the research undertaken in this thesis within the context of existing knowledge. This analysis is undertaken in the context of resource depletion and an increasing concern for sustainability. The chapter also provides a literature review relating to Game theory to show how this can be used as a strategic tool of relevance to this research. It shows that the theory has never yet been so used, and focuses on the Prisoners' Dilemma Game as a vehicle for the strategy and research. Therefore, this chapter shows the research gap within which this thesis falls.

One important consideration for any research project is, of course, the philosophical assumptions on which it is based. These assumptions are generally referred to as ontology, epistemology and methodology. The research in this project is based in a positivist ontology and epistemology, and chapter 3 explains the methodology for the research, and considers the ontological and epistemological positioning, and therefore, provides a framework for the data investigation. It provides a framework for the utilisation of Game theory in the calculus of sustainability in the new environment. It identifies the extensions to Game theory, which are needed to complete the analysis, and explains what empirical data will be used in its analysis. It explains the economic and geopolitical context of the research, and shows why the research looks at both firms within industries and also countries. It explains and justifies the choice of three countries, four industries and various firms, for which the empirical analysis will be undertaken

The next few chapters provide the main analysis of data in support of the arguments in the thesis. So, chapter 4 develops Game theory in a theoretical context, and explains the new extensions developed. These are explained, developed and justified, and the effects calculated on a theoretical basis. From this, conclusions are drawn about what is best for the sustainability of the planet. Then, the role of market regulation is considered to develop the model further. The robustness of the analysis is then tested through the use of linear programming, with appropriate sensitivity analysis. This provides a form of triangulation, and shows the models developed are robust.

Thus, chapter 5 uses real data from the GDP[6] of countries, industry data and the published accounts of firms to show that the theoretical development can be applied satisfactorily in a real context.

Then, chapter 6 considers the analysis undertaken and the implications which can be derived from this. This is in the form of discussion and analysis of the implications for the economic operation of markets and for the necessary factors of productions in a global market of depleting resources. Primarily, geopolitical factors are not considered and the focus is upon the operation and regulation of these markets.

Finally, chapter 7 summarises the research and draws conclusions from the thesis. This is the final chapter and implications of the findings are considered for both practice and for policy; its generalisability, the limitations of the study, the scope for further research, the achievement of the objectives of the research, and the contribution to knowledge made by this thesis are also considered.

1.7 Chapter summary

This chapter has explained the outline of the scenario with which the planet is faced, and upon which this research project is founded. It explains the method of research undertaken, as well as the contribution to knowledge which is being made; These will all be explored further in the remaining chapters, commencing next with an analysis of the existing literature relating to the economic and social environment.

[6] Gross Domestic Product

Chapter 2

Literature Review

2.1 Summary

This chapter presents an overview of the discourse of sustainability insofar as it relates to the future availability of minerals obtainable for extraction and processing. In doing so, it discusses the available data regarding supply of minerals, and rate of depletion, and the strategic reaction of firms and governments to this depletion. This includes the strategic planning in response to doubts about future availability of such minerals. It also considers the use of Game theory as an analytical tool in the investigation of such minerals' depletion. The argument in this chapter is that there are finite supplies at a global level, and that any effects, actions and reactions need to be considered at this level. In achieving this, the chapter highlights important gaps in the research which has been undertaken.

2.2 Introduction

It is undisputable that the laws of physics cannot be changed, and that a prime law states that matter can neither be created nor destroyed.[7] It is equally true that humanity, currently, only has access to the resources of this planet, although it is assumed here that all resources are available, no matter where on the planet they are located. This will of course include minerals located under the sea or in Antarctica which are currently not accessible. It is recognised that minerals can be artificially created, through chemical reaction, but this is ignored as the creation of one mineral can only be at the expense of other materials of the planet and with energy consumption and by other products also being involved. Equally it is recognised that off planet resources exist (e.g. on nearby asteroids) but these too are ignored as not being currently viably accessed. It, therefore, follows that the resources of the planet are fixed in quantity and can only be used once – or at least once in any particular time. This implies that the available resources, and particularly mineral resources, are important, as they cannot be extended in the way that ecological ones can. The amount of any particular mineral available for extraction is not known with any certainty, and various bodies have sought to estimate

[7] The Law of Conservation of Mass-Energy was discovered by Antione Lavoisier in 1785.

these. Mostly, these estimates are available for individual minerals, and examples below detail this. Total availability is also monitored by the US Geological Survey, which publishes reports, at least annually, of all minerals of interest to them (and hence, to the rest of the world similarly) (see pubs.er.usgs.gov/publications). Equally, estimates are made by academics for individual minerals, and occasionally in total (e.g. McCullough & Nasser, 2017). These are reported in Tables 2.1 – 2.7.

Indeed, the exhaustion of mineral reserves is a matter of strategic concern to various organisations. For example, the Hague Centre for Strategic studies produced a report in 2010, with figure 2.1 within, and showed that a number of minerals will be exhausted within a generation, and that this matter needs to be addressed.

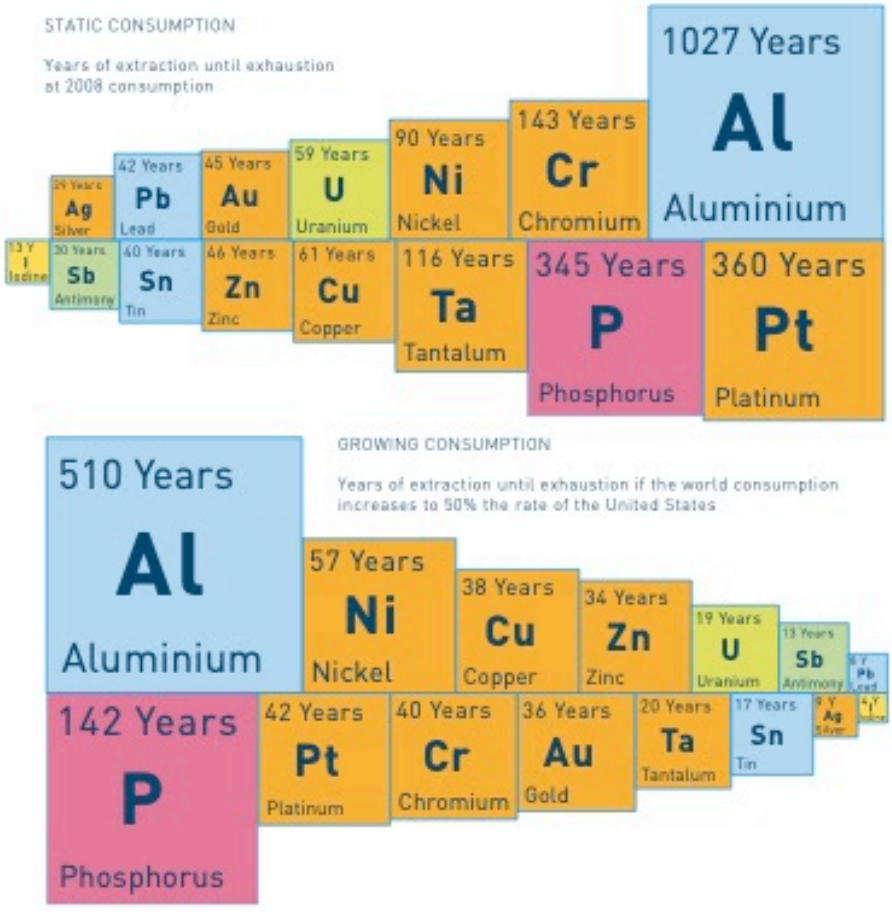

Figure 2.1 – Estimate of time to extinction of mineral reserves (source: Scarcity of Minerals: a strategic security issue; Hague Centre for Strategic Studies no 02/01/10)[8]

[8] https://hcss.nl/sites/default/files/files/reports/HCSS_Scarcity_of_Minerals.pdf

However, no-one is certain of the exact amount of any mineral remaining, due to the unknown quantities yet to be discovered, and many researchers deny that there is a problem. Figures and arguments are discussed below. However, of particular concern is the relationship between available resources and human activity, as it can be expected that as economic activity changes, then mineral requirements can be expected to change roughly proportionally. Human economic activity has been expanding steadily at the rate of 3.0% per annum, and is expected to continue at the steady rate of increase, as the following table shows:

Year	**$ billion**
2000	33581
2005	47459
2010	66036
2015	75003
2017	80891
2018	85804
Projected:	
2019	86599
2020	90519
2023	105786

Table 2.1 Nominal gross world products (GWP)[9]
Source: extracted from www.StatisticsTimes.com (8/1/2020)
Actual figures are from World Bank. Future projections are from IMF

There are, of course, a variety of estimates of economic activity throughout the world, and the figures are imprecise by their nature, but there is no dispute that economic activity has increased, and will continue to increase, despite possible setbacks due to pandemics such as COVID19. It is acknowledged that the French degrowth movement are arguing (Demaria et al., 2013) that a more sustainable future will imply different economic activity but it is unclear that this will either become accepted policy or have any impact upon GDP, and so is ignored. There are, of course, many activities which are encapsulated within these figures, but it can be

[9] Gross World Product – a summation of national GDPs

projected that, as economic activity increases, so too does the need for extractive minerals, as is illustrated by the figures below.

It is equally known that the population of the world is continuing to increase over time:

Year	Billions
2000	6.15
2005	6.54
2010	6.96
2015	7.38
2018	7.63
Projected:	
2020	7.80
2030	8.55
2050	9.77

Table 2.2 – World population
Source: www.Worldometers.info[10]

The rate of increase is running in excess of 1.0% p.a., although projections suggest this slowing to around 0.6% by 2050, at which point, it is expected to be a population in the world approaching 10 billion. Inevitably, as population increases, then economic activity increases, thereby increasing the demand for extractive resources. This will happen due to population increase, even without any economic development, which too will increase demand. However, at the same time as population growth, life expectancy has also increased.

[10] Worldometers is cited as a source in over 3500 published books, in more than 2000 professional journal articles, and in over 1000 Wikipedia pages

Year	Life expectancy (years)
1970	58.7
1990	65.4
2000	67.7
2005	69.1
2010	70.7
2015	71.9
2017	72.2

Table 2.3 – Average life expectancy at birth
Source: The World bank https://data.worldbank.org/indicator/sp.dyn.le00.in

It can be considered that increased life expectancy indicates increasing economic prosperity and increased sophistication, as there is a relationship between these factors (Sen, 1999; Cockerham, Hattori & Yamori, 2000). These also can be expected to increase demand for minerals.

This can be illustrated by some consideration of the production levels of minerals. Thus, oil production has continued to increase, despite the increased production of energy from other sources, particularly renewables. At the same time, renewable energy production has increased by 117% since 2000 (IRENA, 2018), but has remained at around 14% of global energy consumption (Le Page, 2017). At the same time, global energy demand has grown by 65% (BP, 2018), explaining the increase in oil production.

Year	Average per day Thousand barrels
2000	68526
2005	73595
2010	74887
2015	80755
2018	82844

Table 2.4 – Oil production
Source: US Energy Information Administration www.eia.gov/totalenergy/data

Figures are often in dispute, and OPEC (2019) show that production of oil in the period 2009-2018[11] has been 265.9 billion barrels, while additions to reserves have been 210.8 billion barrels. However, their main concern is to show the strength of reserves of their own members. A company, such as BP (2019), argue that reserves equate to 50 years of current production, ignoring the problems of extraction defined by Hubbert (see section 2.5.2), and seeming to imply that 50 years is far enough into the future to be of no concern. Although it is generally recognised that oil is finite in quantity, there seems to be no recognition of any impending shortage of supply. Although the Oxford University Smith School of Enterprise and the Environment has created a "stranded assets programme" to consider assets which are no longer needed in the environment in which they are located, this is not considered to be relevant to this thesis which is concerned with the total quantity of each mineral existing on the planet no matter where located.

Equally, the demand, and hence, rate of extraction of other minerals has increased significantly. This has led to an interest in the circular economy, and how minerals can be better utilised, but there is little data concerning the remaining amount available in the world, and any other considerations of how it can best be used in a sustainable way. For example, both the World Economic Forum (WEF) (2014) and the Ellen MacArthur Foundation (2015) have focused upon their contributions towards a circular economy (section 2.6), rather than any impending scarcity, although the WEF (2014) have recognised the need to source minerals from more inaccessible locations.

The most available data on actual mineral reserves and their extraction is provided annually by the US Geological Survey (which is assumed to be the least biased).

Thus, tin production has changed:

[11] https://www.opec.org/opec_web/en/data_graphs/331.htm

Year	Extraction '000 tonnes	Reserves remaining '000 tonnes
2000	238	9600
2005	290	6100
2010	265	5200
2015	289	4800
2018	310	4700

Table 2.5 – Global annual tin extraction
Source: US Geological Survey
https://www.usgs.gov/centers/nmic/tin-statistics-and-information

These figures are in dispute, and ITRI (2016)[12] report that in 2015, extraction was 306000 tonnes, with reserves at 2200000 tonnes. In the report, they point out that their objective is "to reassure all those concerned about tin supply" (page 4). This is one of the problems with accessing data, that the data is disputed, and much is produced for a specific purpose.

Thus, world copper extraction has increased similarly:

Year	Extraction '000 Tonnes	Reserves remaining '000 Tonnes
2000	13200	340000
2005	14900	470000
2010	16200	540000
2015	18700	700000
2018	21000	790000

Table 2.6 – Global annual copper extraction
Source: US Geological Survey
https://www.usgs.gov/centers/nmic/tin-statistics-and-information

For lead, the data reveals the following:

[12] https://www.internationaltin.org/wp-content/uploads/2018/01/ITRI-2016-Report-on-Global-Tin-Resources-and-Reserves.pdf

Year	Extraction '000 Tonnes	Reserves '000 Tonnes
2000	2980	64000
2005	3280	67000
2010	4100	80000
2015	4910	89000
2018	4400	83000

Table 2.7 – Global annual lead extraction
Source: US Geological Survey
https://www.usgs.gov/centers/nmic/tin-statistics-and-information

Therefore, it can be seen that economic activity is increasing on a global level, and so too is the rate of extraction of minerals. At the same time, estimated reserves are changing. The problem is that, with absolute certainty, the amount available in the world is finite, and as it is extracted and used, then the remaining reserves must be reducing. At the same time, the amount remaining is really unknown, and the figures quoted are based upon estimates. Thus, from the above it can be seen that some known reserves are reducing, while others are increasing. Nevertheless, the finite amount available for future use must be reducing, although there is some uncertainty as to remaining quantity of reserves. This is partly the justification for this thesis, and there is the need to plan for use of the remaining resources by controlling the depletion rate to ensure sustainability.

More recently there has been considerable attention paid to the rare earth metals, their scarcity and essential need to manufacture many technological products. While there is some concern about their availability due to geographical location of the metals there is no concern about their availability on the planet (Boer & Lammertsma, 2013). Dodson et al. (2012) argue that any scarcity is a political issue as countries compete to secure available supplies while Tukker (2014) argues that it is only market failure which is causing any scarcity of these metals. Such issues have meant that analysis of these metals has been excluded from the analysis in this thesis and more commonly used minerals have been considered. It is of course argued that the analysis would apply equally to any extractive resources from the planet.

Next, we discuss the depletion of resources using Gaia Theory.

2.3 The Gaia Theory

Building on his earlier work (Lovelock & Margulis, 1974), in 1979 James Lovelock published a book setting out the Gaia Hypothesis (Lovelock, 1979), named after the Greek goddess of the Earth. In this hypothesis, he proposed a different model of the earth in which all living matters are dependent on each other. According to this theory, a complete system is formed in which all components are equally essential for preserving earth as a planet. Moreover, it is a homeostatic system, which maintains itself in equilibrium (Onori & Visconti, 2012).

The Gaia theory was completely radical departure, depicting an extensive interdependence. Not surprisingly, it was scorned - in a true Kuhnian sense of a proposed paradigm shift (Kuhn, 1962) - when it was first proposed. Lovelock continued to demonstrate the validity of the hypothesis, and it has now gained general acceptance (e.g. Volk, 2003), and is often now referred to as the Gaia Theory. Until recently, Lovelock and his supporters continued to maintain that this system of the earth and its components was a homeostatic system, which would maintain itself in equilibrium, and would continually return to that equilibrium. This was convenient for politicians and others, as it meant that climate change and other changes to the ecosphere were not a cause for concern. More recently, however, Lovelock (2006; 2015) has claimed that the system is no longer in equilibrium and will not return to the same equilibrium position, although it may revert to a different equilibrium when we limit the changes imposed upon the system. In other words, mankind is making irreversible changes to the planet and its ecosphere.

It is generally accepted that current economic theories are based upon the tenets of classical liberal theory, as adapted by Bentham (1834) into Utilitarianism, and are concerned with how to make the best use of scarce resources (Marshall, 1890). Utilitarianism has been debated extensively (e.g. Riley, 2006), and challenged as to its implications. One implicit assumption in this approach is that nature is a resource to be exploited in the pursuit of wealth creation. The Gaia Theory stated that all organisms were interdependent within a homeostatic system. Moreover, it is imperative to realize that any action by a single firm can impact other firms. There is a high possibility that an action of a firm, unintentionally impacts or causes harm to another firm, just as national actions have such implications. In short, any action may have unintentional outcomes (Gleick, 1988), while Parker & Stacey (1995) extended this to argue

that human activity, particularly in relation to business activity, represent non-linear activity, which is essentially unstable.

2.4 The Brundtland Report

In 1983, the World Commission on Environment and Development (WECD) was formed by The United Nations, under the leadership of Gro Harlem Brundtland. Later, the organization's name was changed to the Brundtland Commission, which published the well-known Brundtland Report (WCED, 1987). This Commission was aimed at addressing a rising concern, regarding the rapid deterioration of natural resources and earth's environment, and the impact of these two on social and economic development. The UN realized that environmental degradation is a global phenomenon, and that to work for preservation of environment is in the best interest of all nations. The Brundtland Report stressed the need to take measures, which ensure sustainable development, without excessive depletion of natural resources or any negative impact on the environment. This was for the first time that environmental issues were recognised at such a level, although earlier concern had been raised about this, and is generally considered to be started by Rachel Carson (1962) with her seminal book: "Silent Spring". The Brundtland Report centred primarily around securing global equity, and the redistribution of resources from developed to poor nations, while encouraging economic growth. The idea put forward by the Brundtland Report was that it is possible to have environmental preservation, economic growth and equity simultaneously, known as the three pillars of sustainable development, and later as the Triple Bottom Line (Spreckley, 1981; Elkington, 1997). It was also recognized in the report that social and technological change is imperative to achieve such an equity and sustainable economic growth.

The Brundtland Report provides what has become the standard definition of sustainable development:

> "Sustainable development refers to the kind of development, which meets requirements of modern world without adversely or negatively impacting the ability of future generations to fulfil their needs. Two central concepts are presented in this definition of sustainable development:
>
> • The idea of **needs**, particularly the basic needs of world residing in the poorest regions. These people are the ones, whose needs are to be fulfilled on primary basis.

- The concept of **limitations,** arising because of social organizations and technological advancement level on the ability of environment to fulfil future and present needs." (1987: 16)

Five years later, in 1992, a conference was held in Rio de Janeiro. The conference, called the United Nations Conference on Environment and Development, later became famous as the Earth Summit. Participants in this conference were delegates from 172 countries, 108 of which were the heads of governments or countries. Moreover, more than two thousand people were delegated by NGOs, and there were more than 15 thousand people with consultative status attending the parallel sessions. This conference had an important outcome which was the agreement on the Climate Change Convention, and it led to another achievement which was the Kyoto Protocol. This agreement was arranged in the United Nations Framework Convention on Climate Change. Countries which joined in this agreement are committed to lower carbon dioxide emissions and five more greenhouse gases. Alternatively, if they keep their emission levels or do not lower their emissions, they get involved in what is called emission trading. The protocol was adopted in 1997 and ran from 2008 until 2012. The USA did not sign the protocol, and Canada withdrew in 2012. It was succeeded by the Doha Amendment in 2012. This has been modified several times and is currently known as the Paris Accord (2016), agreeing to limit climate change to 1.5º Celsius. This has been signed up to by almost all nations, although it is perhaps significant that the USA, under the leadership of Trump, has recently decided not to be included. Currently, however, all signatories claim to be taking the necessary steps to comply, although this is disputed by many (e.g. Extinction Rebellion https://rebellion.earth).

The other agreement was about the lands belonging to the indigenous people, and accordingly, it was agreed not to do any activities in such lands that might be environmentally harmful, or that might be considered inappropriate culturally. Also, The Biological Diversity Convention started at this conference (in 1992), with the aim of redefining measures for money supplies, which would not destruct natural ecology or lead to non-economic growths.

Agenda 21 was another outcome in relationship with sustainable development[13]. The number 21 is used to declare our century and the aim was to imply its long-term and futuristic

[13] https://sustainabledevelopment.un.org/outcomedocuments/agenda21

expectations. This agenda lists the measures to be taken by governments and nations and the UN in the fields of their impact on their environment. It specifies three key points as information, integration, and participation, which would assist countries in attaining sustainable development, which includes its interdependent pillars. The emphasis of this agenda was on that, for sustainable development, everybody uses and provides information, and that the traditional sector-oriented ways of doing business should be changed with modern ways involving cross-sectoral co-ordination, and that social and environmental concerns should be integrated into all development processes. Besides, the emphasis was on decision-making through public participation in broad scales, as a key requirement to attain sustainable development.

On the 20th anniversary of the release of the Brundtland Report, the World Business Council on Sustainable Development (WBCSD 2007) provided a report of its own – Then and Now: Celebrating the 20th Anniversary of the Brundtland Report – which provided an update on the progress made in the intervening years. The WBCSD report gives an account of the Brundtland report but focuses, particularly, on how the WBCSD has developed itself as the business voice in the sustainable development arena and what actions they have taken towards the future. Although, it is primarily about self-promotional, this report shows that the WBCSD has made some positive efforts over the years since Brundtland. Nevertheless, it also highlights that nearly 30 years after the original report, almost everything in the original report is still relevant today, including the warning about climate change. There is some cause for optimism, though, as climate change is now more of an accepted fact, and global warming has entered popular consciousness as a cause for concern. Indeed, Hauff (2007) concluded that the main missing ingredient was management and co-ordination between public and private sectors. So, perhaps pressure from individuals will lead to the action, which has been largely missing for the last 30 years.

Summits and conferences, concerned with climate change, continue to occur on a reasonably regular basis. Indeed, the Paris conference, held in 2015, was actually the 21st such conference. However, this conference led to the Paris Agreement on action to reduce climate change. The agreement would come into force when ratified by at least 55 countries; on Earth Day 2016[14], 174 countries ratified it, and it is now in force. The agreement is to limit global warming to

[14] 22nd April 2016

less than 2ºC, and to seek action to limit it to 1.5ºC. This requires the achievement of zero net anthropogenic greenhouse gas emissions[15] before the middle of the century. The main countries crucial to achieving this are the USA and China, so we await the outcome…

The Brundtland Report and its definition have formed the core of all research into sustainability and sustainable development ever since its publication (see for example Daly, 1990; Sneddon, Howarth & Norrgaard, 2006; Aras & Crowther, 2008b). This has implications for resource depletion (Whiting et al., 2017), as choices for future generations are inevitably restricted.

2.4.1 Sustainable development

Sustainable development is accepted generally to be a process aiming to satisfy human requirements, while keeping the natural environment high in quality indefinitely. Although many might think that it was Brundtland who first mentioned this kind of development, in fact, the term sustainable development was used in the report, World Conservation Strategy, as the International Union for the Conservation of Nature had recognised the relationship between development and environment in 1980 (Purvis et al., 2018). However, undoubtedly, it was after the Brundtland Report's publication that this term became ubiquitous.

The Brundtland definition for the three pillars of sustainable development is not the only definition used, for instance, ISO central secretariat (2006) considers standardization, metrology and conformity assessment as the three pillars of sustainable development. On the other hand, Lindsey (2007) claims that in many instances, standards have so far supported legislation, but the role of standards in this area can be even wider and greater, while Arushanyan et al. (2017) propose a framework in which these can be applied with a heavy concentration on qualitative assessment.

According to Aras & Crowther (2008a), what is implied by sustainability is to accept whatever cost is involved today, to invest for tomorrow. In fact, the concern of sustainable development is about the effect of actions taken today on options available tomorrow. In a sustainable society, the needs of the society are provided without affecting what in future might be needed by people. Thus, in a sustainable society, resources used should not exceed what is regenerable

[15] In other words, emissions caused by human activity.

– which is of course only possible if resources can be regenerated, and not for the extractive resources with which this thesis is concerned. The recent globalization movement means that this need is even stronger. In order to achieve globalisation, the world needs to integrate, hence higher need to standards in international level – instead of national – to avoid them be used as trade barriers. Although this is not disputed, the problem seems to be (Bansal, 2002) that businesses do not know how to enact this.

Market globalization expansion means (Borghesi & Vercelli, 2003) that international standards – and not the national or regional ones – are getting more and more important for businesses, when exports and imports can be traded, while meeting safety and performance requirements in the international level. Through improved safety, compatibility and quality, international standards for production and products, and also for services play a big role in facilitation of trade, and also on sustainable development, and the world is significantly benefitted from this. While a society can be benefitted from improved environment and health and good practice in regulation and sustainability, standardisation will support trade internationally as well (ISO central secretariat, 2006).

The UN continues to promote sustainable development and now focuses upon Agenda 2030 as a plan of action[16]. This is supported by 17 SDGs (sustainable development goals). This is of course pertinent to future actions and will affect the planet but a distinction must be made between sustainable development and sustainability. Sustainability is the focus of this thesis and sustainability in itself does not imply any development. It is for the inhabitants of the Earth to decide upon what level of development is required. In this thesis, the focus is upon the argument that sustainability is facilitated by the use made of the remaining minerals, and how they are distributed throughout the planet.

The idea of globalisation encourages countries to adopt harmonised rules (Tisdell, 2001) in a continuing process[17]. Unless otherwise, they will be trapped in diverse, and sometimes conflicting rules, which would result in unequal trade market. International standardisation is an ideal opportunity for the countries to raise their voices on the matters, which otherwise, may

[16] https://sustainabledevelopment.un.org/post2015/transformingourworld

[17] See for example DIRECTIVE (EU) 2019/771 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 May 2019 on certain aspects, concerning contracts for the sale of goods, amending Regulation (EU) 2017/2394, and Directive 2009/22/EC, and repealing Directive 1999/44/EC, which was part of the continuing aim of improving the operation of the “Single Market”

become barriers to their trades with the world. So, countries should necessarily participate actively in the process of international standards drafting. This is, indeed, of vital importance for the developing countries, who could make sure that their national conditions are observed. So, they would willingly meet the international standards, formulated through a consensus approach. Besides, use of international standards is beneficial in avoiding unnecessary costs to provide national standards, which may result in other barriers to trade. Spending time and money on already established international standards at national level is just as reinventing the wheel. Therefore, the worldwide trend is to adopt international standards in order to realise the aim of "one standard, one test and one conformity assessment procedure, which is accepted everywhere". However, it is worth mentioning that "development is not a one-size-fits-all process. Each country must progress, as ultimately only it can best tell what its ambitions and needs are. However, in a globalisation world, sustainable development cannot be achieved in isolation (Sudarwo, 2008).

2.5 Depleting resources

Given that we have only the resources of one planet, then it is axiomatic that the available resources are finite in quantity, as the Law of Conservation of Mass states that matter can neither be created nor destroyed[18], and this has resulted in the definition of resource depletion. This can be defined as the consumption of resources at a faster rate than they can be replenished (Hook et al., 2010). For renewable resources, this is measured by Earth Overshoot Day (see chapter 1). For extractive resources, these can only be replenished over millennia, as nature is transformed into minerals such as oil and coal, and so are effectively fixed in quantity, and essentially non-renewable; indeed, minerals such as metals cannot be created at all, and so certainly they are fixed.

Given that the quantity of extractive resources is fixed, then it is tautological that the use which can be made of them is also fixed and determined by the amount which can be extracted from the earth, coupled with the amount which can be reused or recycled. This puts a limit on the economic development of the earth, and needs to be considered within the context of sustainability (see, for example, Schneider, Kallis & Martinez, 2010). It was reported, as long ago as 1975 (Engelhardt, 1975), that the rate of extraction of metal resources had increased so

[18] Discovered by Lavoisier in 1785

dramatically that availability was becoming a problem. Some concern has been expressed ever since, although there is no opinion that there is any particular problem (see Crowson, 2011). Indeed, Meinert, Robinson & Nasser (2016) specifically state that any projections of impending shortage in the next 30 years are wrong. Yaksic & Tilton (2009) concur with respect to lithium. Contrarily, however, Tilton & Lagos (2007) argue that future availability of copper supplies is dependant upon demand, based on such unknown factors as technological change. So, any claims of finiteness of supply limiting availability are not generally accepted, although there is some questioning.

The extent of reserves, existing in the world, is not known with any certainty. Indeed, the extent of undiscovered reserves, under the sea and in Antarctica, is still to be discovered, but is thought to be significant (Petersen et al., 2016). The existence of reserves and their availability are not the same, and there are a number of factors which limit their availability:

a) Technological factors – some reserves are not available, because the technological expertise does not exist to extract them (Matos, 2007). Presumably, they will therefore become available at some point in the future.

b) Economic factors – price of the material determines whether or not it is worth mining. As price rises, then it becomes more attractive to mine previously uneconomic resources, and so a rise in price leads to an increase in supply (Evatt, Soltan & Johnson, 2012), although Marvasti (2000) argues that size of reserve is more important than price in any decision to begin exploitation. Conversely, Lusty & Gunn (2015) argue that shortages will lead to technical innovations in extraction, which will overcome any shortages, but fail to recognise the ultimate finiteness of available resources.

c) Environmental factors – the location of some reserves means they cannot be extracted because of environmental consequences. Examples would include unstable environments (e.g. the likelihood of fracking, causing earthquakes (Ellsworth, 2013; McGarr et al., 2015)), or environmentally risky locations such as seabed mining (Levin et al., 2016). It might also include nearness to important sites, or major human inhabitation necessitating something such as a social licence to operate.

d) Political and geo-political factors – political unrest or conflict can limit availability (e.g. the sanctions by USA against Iran limits oil supply, and similarly, unrest in Venezuela limits supply). In some cases, political disagreement limits supply from one country to another (Haglund, 1986; Tekin & Walterova, 2007; Gemechu, Sonnemann & Young, 2017).

2.5.1 Geopolitical considerations

One factor to consider is the location of all mineral reserves, and a significant proportion of them are located in the BRIC countries (Brazil, Russia, India, China). They are also countries with large populations, and which are achieving rapid economic growth and development, using, inter alia, their mineral resources (Wilson, 2015).
A review of resources available in these countries (Sidaway, 2012) reveals potentially significant problems. China – the largest country in the world, as well as the fastest growing in terms of GDP – has deposits of most of the 150 minerals found so far in the natural world (Clark et al., 1987). It has the largest deposits of 12 minerals, and large proportions of 45 more. Brazil has large quantities of mineral resources such as quartz, diamonds, chromium, iron ore, phosphates, petroleum, mica, graphite, titanium, copper, gold, oil, bauxite, zinc, tin, and mercury. The main natural resources of India are iron ore, bauxite, and copper ore. India is one of the major producers of iron in the world. Gold, silver, and diamonds make up a small part of other natural resources available in India. Russia has the world's largest mineral and energy supply, and has 22% of the world's oil, 16% of the world's coal, and 40% of the world's natural gas. It also has largest quantities of minerals such as iron ore, nickel, gold, diamonds, zinc, aluminium, tin, lead, platinum, titanium, copper, tungsten phosphates, and mercury (Dubrinski, 2013; Dudin et al., 2016).

It might be argued that the rapid development of these countries has slowed in recent years – indeed, it might be argued that they have slipped into recession, with either zero or negative growth (Degaut, 2015). Nevertheless, their economic activity uses significant amounts of their resources, thereby lessening the amount available elsewhere, such as in Europe.

2.5.2 Extent of remaining resources

Currently, it is known what proven and estimated reserves exist, but there has been some

concern as to what remains and how long it will last. Indeed, it has been recognised by some for many years that shortages of materials and energy will become greater, as supply problems and environmental effects mount up. Thus, Harmon (1977) argued that understanding the true nature of all related costs has become paramount. More recently, various researchers have attempted to calculate the length of time for which some minerals will remain (see for example Meinert, Robinson & Nasser, 2016; Henckens et al., 2016a). Thus, in 2001, Tilton calculated that based upon a 2% increase in annual demand, these minerals would last for:

Mineral	Remaining years
Aluminium	48 years
Copper	22 years
Iron	65 years
Nickel	30 years
Silver	15 years
Tin	28 years
Zinc	20 years

Table 2.8 – Estimation of remaining years to exhaustion of minerals

These figures differ from those of Table 2.1 due, in part, to different assumptions about extraction rates and changes in demand. It also illustrates the lack of certainty about actual amount existing on the Earth and amounts which are recoverable.

According to ITRI[19] (2016), proven global reserves of tin will last for a minimum of 7 years, but calculated reserves will last for a minimum of 36 years, based upon 2014 levels of use, which is similar to the figures calculated above. On the other hand, the US Geological Survey estimated in 2019 that tin would last for a further 15 years (see Table 2.5). It must be recognised, however, that there is considerable uncertainty regarding total recoverable reserves and future demand.

Given that a significant amount of time has passed since these calculations, and growth may

[19] Industrial Tin Research Institute

well have surpassed the 2% forecast, then supplies must be getting short of some of these. More recently, Science Focus (Anon (a), 2019) reported that there was a serious threat to the supply of 30 minerals, many of which are necessary for the production of technological goods. Similarly, Desjardins (2014) has forecast that, based upon current usage reserves of lead, zinc and silver will be exhausted by 2030 and copper by 2040. It is, of course, not fruitful to seek to obtain exact dates or to debate whether any such impending shortages are real or illusory. However, it is pertinent that total supply is fixed, and once used, is no longer available. This requires some action.

Contrarily, the US Geological Survey (2019)[20] estimated that copper would last for 39 years. Although the rate of extraction has been increasing, the estimated amount of recoverable reserves has also been increasing. Thus, they record that since 2000, the rate of extraction has increased by 62%, while the total recoverable reserves have increased by 259%. Similarly, the US Geological Survey (2019)[21] estimated that lead will be fully extracted in 18 years. Therefore, it can clearly be seen that there is considerable uncertainty in availability of minerals and time until exhaustion. Nevertheless, it must be recognised that exhaustion will occur at some point in the future, which might not be too far away for some minerals. It must also be recognised that as reserves become more depleted, then the physical difficulty of extracting them – and the cost thereof – will also increase, which also may limit supply availability (Cairns & Lasserre, 1986; Reynolds, 1999).

Exhaustion has consequences. For example, consider Easter Island. Once the trees had been fully used, then no resource was available as a substitute (Pakandam, 2009), and such activities as sailing had to be terminated alongside the termination of the construction of the famous statues. Of course, trees can be regrown, and therefore, they are replaceable. Of greater concern is the reduced supply of extractive industries, like tin and aluminium, or the shortage in supply of minerals needed in electronics industry. As an instance, the tin which has been the basis for founding the capital city in Malaysia is completely extracted, and now the major part of this industry is devoted to recycling. Tin was the main reason for founding Kuala Lumpur (Gullick, 1983). This is because the UK had already extracted all their tin for many years (Hawkes, 1974), and the prosperous industries related to tin also had all disappeared. Therefore, as a

[20] https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/copper/
[21] https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/lead/

desire to expand, Britain exploited what existed in other areas. By complete extraction of a resource like coal, the related firms will all fade, as will all the related professions. Therefore, people involved in such industries will, obviously, be worried.

On the other hand, lead in the UK had been mined for over 3000 years, but by the start of the 20th century, it was completely exhausted (Burt, 1984; Cooper, 1993). Now, however, the spoil from lead mining is being reworked in order to extract minerals such as fluorspar, which is currently in great demand as a flux and in making enamels (Frauenfelder, 1936). So, it can be seen that recycling for other minerals is a feature of some mining, as is the exporting of mining technologies throughout the world (Pegg, 2006). Conversely, Pirrie et al. (2003) recount how mineral mining spreads the sediment of mining, not all of which is beneficial, throughout the surrounding area. Thus, mining is not necessarily beneficial and can harm sustainability in the natural environment.

Bocken et al. (2014) show, through research, that maximising the efficiency of use of both energy and materials, and substituting their use with either renewables or natural processes is currently considered essential practice by firms in seeking to achieve sustainability. This can be regarded as a step towards the circular economy, which according to Ghisellini, Cialani & Ulgiati (2016), is currently in its early stages, because it focuses upon recycling rather than reusing materials.

One of the main concerns, worldwide, is depletion of oil resources, as energy supplies most of economic activities. Hubbert (1956) proposed a theory about scarcity of resources such as fossil fuels. This theory is generally famous as Hubbert's Peak, and declares that gas and oil production will raise to a peak amount, but quickly afterwards, reduces by shortening of resources. This theory was to justify the future decrease in oil production in America, and has been a subject of much discussion more recently. Thus, Deffeyes & Silverman (2004) mention Hubbert's Peak and discuss about the possibility of its having been arrived at or not. Indeed, Bardi (2009) states that some believe it had arrived in 2005 or 2006, while others considered that it will arrive during the subsequent decade. Recently, however, the discovery of new sources and extraction techniques (such as fracking (see Bazant et al., 2014)) have resulted in less prominence, as the available oil can be expected to last longer.

The important point concerning oil production is not how long reserves will last, but the arrival of what has been labelled "peak oil", which determines the maximum speed at which it can be

extracted. Almeida & Silva (2009) recognise this, and argue that as oil is so crucial for energy production, then serious social and economic problems will arise after this event. Of course, new technologies such as fracking and oil shale extraction have expanded the available reserves, but Chapman (2014), nonetheless, argues that increasing world demand will prevent this increase from solving the problems of shortage. Indeed, Kerr (2012) argues that fracking technology benefits particular countries, particularly the USA, but barely compensates for declines in aging fields on a global scale. Furthermore, Kerschner et al. (2013) point out the difficult economic implications of this. Conversely, the concern with peak oil seems to have disappeared and is considered to be incorrect (Bardi, 2019), despite many maintaining its imminence.

2.6 Reacting to resource depletion

It has been generally recognised that resources are becoming depleted (Vohs & Heatherton, 2000), although there is no agreement as to by how much and by when any of these resources will become no longer available. As a result, as Vincent, Panayotou & Hartwick (1997) claim, a main reason for the existing interest in sustainability is depletion of resources, and in particular energy resources, actual or impending. Of course, depletion does not mean that resources are exhausted, but that they are consumed to such an extent that supplies will soon diminish. Indeed, as they become increasingly scarce, those extractive minerals and metals become more difficult to extract, and therefore, more costly. A number of approaches can be identified:

- **Recycling**

According to Spengler, Puchert, Penkuhn & Rentz (1997) one approach is to recycle the resources that have been consumed. Wilson, Velis & Cheesemen (2006) consider this as a growing business, which can make up for scarcity of resources, but only to a limited extent. Reck & Graedel (2012) report that this is beneficial, but problematic, and that we are far away from any complete recycling of minerals. This is because growth will continually require more of the resource than has been previously consumed. Technological development can lead to less use of the resource, as can the development of substitute resources. These too are limited in extent, and can lead to different resources becoming depleted in addition.

- **Renewables**

Concerns regarding the impact of energy on earth's environment has resulted in an increase in interest in renewable energy resources (Ellabban, Abu-Rub & Blaabjerg, 2014). The sources of renewable energy include geothermal heat, tides, rain, wind, and sunlight and, are naturally replenished. Approximately, 15% of energy consumed worldwide is obtained from renewables, and 10% of this energy is derived from customary biomass, which is major source of heat, and approximately, 3.5% from hydroelectricity. More modern renewables, which include biofuel, geothermal, solar, wind, modern biomass, and hydroelectricity generation at small scale account for an additional three percent, and are accumulating very rapidly. According to Renewables (2011), the part of renewables in generation of electricity is approximately 20%, with more than 15% of electricity around the world coming from hydroelectricity.

Concerns related to climate change, accompanied with hiked oil prices and rising government support, necessitate legislation regarding renewable energy, commercialization and incentives (United Nations, 2007). Another idea put forward during last few decades is to utilize renewable energy as a backup or hybrid system. According to Lynas (2008), if this idea is put to practice, it will be helpful in achieving higher efficiency, even during unfavourable climatic conditions. Hybrid energy is also considered by Horne, Jaccard & Tiedemann (2005), who suggest that tax incentives will be necessary to speed their introduction. Le Page (2017) argues that renewable energy is not increasing at a speed, fast enough to ward off climate change. He points out that only 14% of our energy is from non-fossil fuel sources, and that this has not changed for the past 25 years. Ellis et al. (2007) identified that numerous energy efficient devices from transport to electronic devices are introduced.

- **The circular economy**

It seems to be recognised that achieving sustainability will require some form of market transformation, but Smallbone (2004) concludes that this transformation is a consequence of achieving sustainability, rather than a driver for change towards sustainability. The circular economy is one approach to this transformation, and is based upon a combination of reducing, recycling and reusing (see World Economic Forum scoping paper 2014[22]), but Wilts (2017)

[22] http://www3.weforum.org/docs/WEF_MM_MiningMetalSustainableWorld_ScopingPaper_2014.pdf

points out that this is problematic to actually implement. The Ellen MacArthur Foundation (2015) recognises that resources are becoming scarcer, but argue that this transition will decouple economic development from resource consumption, without providing evidence for this assumption. At the moment, therefore, it remains a fashionable concept – rather than any real solution – although Haji & Slocum (2019) have proposed the repurposing of disused oil rigs in the Gulf of Mexico to extract cobalt from the sea, and thereby create material for batteries.

The concept of the circular economy is based upon reducing waste (Vilarfino et al., 2017), including the transforming of waste into energy (Pan et al., 2015). Although recycling is increasing over time, so too is mineral extraction, as economic growth is also increasing. The concept of the circular economy may slow the rate of depletion, but cannot halt it, and not all mineral can be recycled, as some is lost through wear and tear. Additionally, recovery and recycling can be aided by technological development, but will still need energy to be produced in order to effect any transformation. Thus, it may be possible to make some minerals totally reliant upon the circular economy, but this is not possible for all minerals in combination. It seems that this is not yet being recognised.

- **Reusing / ecological approach**

There exists a number of small businesses, which have adopted a nature-centric approach to business and tried to fit their operations into an ecologically sustainable business model. Interestingly, Kearins, Collins & Tregidga (2010) describe some such organisations, depicting how they are not always successful in achieving such ecological sustainability for a number of factors. They also assert that such businesses are all small in size, and describe them as visionary, thereby accepting that this is not the norm. Of course, such models are not appropriate for extractive industries, which must be large in scale and cannot readily be ecologically sustainable, although Emel, Angel & Bridge (1995) suggest some steps which are being taken towards greater sustainability in environmental effects. Networking seems to be a key part of any such strategy (Heuer, 2011), which seems to be a common form of organising among small scale enterprises, but not among larger ones. This can, possibly, be regarded as an embryonic form of cooperation, discussed in this thesis. Baranchenko & Oglethorpe (2011) go further and argue that the cooperative form of enterprise achieves environmental efficiencies, and that this form of organising may be a valuable aid to sustainable development

policies – but only as a future possibility. Goodman, Korsunova & Halme (2017) also consider collaboration as important, and outline a collaborative perspective of stakeholder theory to argue that secondary stakeholders may be more important for sustainable innovation than primary stakeholders. However, Lovelock (2009) points out that irreversible changes are already taking place to the planet and its balance, suggesting that the measures being considered and undertaken are too little and too late; current evidence from NASA seems to support his argument.[23]

Studies of the effects of depletion can be classified into a number of varieties:

- **The tragedy of the commons**

Many have studied the tragedy of the commons and the problems that ensue. Indeed, recently Thuestadlsaken, Brekke & Richter (2019) have demonstrated experimentally that there is always a tendency to exploit the contributions of others rather than to reciprocate. Alfaki (2013), similarly, uses Game theory to show that increased risk in obtaining supplies leads to increased consumption and selfish behaviour. The tragedy of the commons is often used to study environmental resources and their use. Thus, Gersani et al. (2001) use Game theory to show that soybeans compete for space with other species and plants as far as possible. Conversely, Rankin, Bargum & Kokko (2007) study competition in biological systems to show adaption strategies, but still question the extent to which anything supercedes self-interest. On the other hand, Botelho et al. (2015) suggest that sometimes cooperation can arise to mitigate the effects of resources shortage in a common pool resource, but only model circumstances in which there are relative similarities in size and power between the actors in the model. Similarly, Janssen (2015) shows that complex behavioural circumstances are necessary to facilitate cooperation in common pool resources.

- **Exhaustion studies**

Surprisingly, the question of the exhaustion of natural resources is not a new topic, and was first considered more than 150 years ago, when Jevons (1865) argued that coal stocks would become extinct, while outlining his paradox. Similarly, almost one century ago, Hotelling

[23] https://climate.nasa.gov/evidence/ (accessed 4/5/2019)

(1931) analysed the economics of the exhaustion of natural resources. Unfortunately, or perhaps expectedly, due to the time of his analysis, he considered that this can be dealt with through the price mechanism, to determine the optimum usage of that resource. Again, due to his time of writing, he did not consider a global exhaustion of the resource, and was more concerned with specific examples, such as the extraction of all useable minerals from a mine. Moreover, he did not recognise that the price mechanism will result in a solution which is best for the owner of that resource, but when a global situation is considered, it can be seen that what is best for the owner of the resources is not necessarily what is best for the world at large. Nevertheless, this led to a strand of research within economics, where such a scenario has been considered. Perhaps, most relevant are those researches which considered a closed economy. For example, Solow (1974a; 1974b) considered the survival of a country, when its resource is fully utilised, but argued that it depended upon the extent of availability of substitutes and the extent of technological development. Similarly, Kemp et al. (1984) argued that without the availability of substitutes, technological development was needed, but could be assumed to happen, and that therefore, the future would solve current problems. Others have considered the renewable resources, and a summary by Kerry Smith (2009) shows that no-one is really addressing long-term implications. Others (e.g. Harris, Howison & Sircar, 2010; Ludkovski & Sircar, 2011) have applied Game theory to the problem, but have sought to resolves only the problem of price and production levels or the attractiveness of substitutes. Therefore, it seems that planetary exhaustion has not been researched.

- **Extinction studies**

The extinction of anything has only been investigated in a local context, concerning animal and plant species (e.g. Runge, 1981; Kotler et al., 2002). In effect, these are a variety of the tragedy of the commons' analysis, and do not apply at a global level. Other research has focused upon international borders and access to resources (e.g. Dombrowsky, 2007), or with conflicts resulting therefrom (e.g. Boddewyn & Brewer, 1994), or their resolution. Others have investigated the dealing with particular countries to acquire resources by multinationals (e.g. Jansson, 2008), and the political problems resulting therefrom (e.g. Wilson, 2017). Much of this kind of analysis focuses on geopolitics, at a national or regional level, and does not look at the world as a whole. Interestingly, such analysis does not generally make use of Game theory, and there is a clear gap in this respect.

- **Global resources**

There has been considerable research, investigating water resources and conflict over access – see for example Uitto & Duda (2002); Yoffe, Wolf (2007). There is also some research (e.g. White, 2007) concerning sharing of ecological resources and sustainability. Some concern is evidenced regarding sources of energy, and Chow, Kopp & Portney (2003) make the point that even renewable resources are not without environmental effects. However, all concern seems to be with the environment rather than actual availability of resources. Thus, for mineral resources, any concern over shortages is refuted by Arndt et al. (2017), who argue that better mining technologies mean that there is no impending shortage. Significantly, this only moves any problem into the future, as the total quantity remains finite, no matter what technological improvements take place. Indeed, Adelman & Watkins (2008) refute the whole theory of defining the exact extent of mineral reserves, while pointing out that no matter how much reserves are discovered, the available supply on the planet remains finite.

Therefore, it seems that there is no consensus regarding the depletion of resources on a global basis, and no concern regarding the finite nature of these resources. Indeed, there seems to be a complacent assumption that technological changes will take care of any problems, and a total disregard for the Jevons paradox[24] (Jevons, 1865; Alcott, 2005). Indeed, Zuttel et al. (2010) negate this, and describe hydrogen as the energy source of the future, claiming that its use is CO^2 neutral, although their argument seems to ignore the Second Law of Thermodynamics[25].

2.7 Manufacturing and the external environment

During the previous few decades, it has been recognised that the external environment is affected by the activities carried out by a company. This necessitates the accountability of the company, not just to its shareholders, but also to a greater audience. Although initially propounded by such philosopher entrepreneurs as Owen (1816), this necessity was initially revived during the 1960's, after Rachel Carson's work (1962), and further propounded during the 1970's, and some authors have considered the firm's social performance as a member of

[24] The Jevons paradox occurs when technological progress increases the efficiency with which a resource is used, but the rate of consumption of that resource rises due to increasing demand.
[25] This law states that total entropy can never decrease, and will only remain stable if the system and its surroundings remain constant. In other words, heat from the energy conversion will increase entropy, and thereby cause environmental effects.

the whole society. Ackerman (1975) argued that majority of the large-scale businesses have already realized the need to adjust with the recent social environment of accountability towards community, but that the alignment of business to financial outcomes is a constraint for this. In the same way, McDonald and Puxty (1979) argue that shareholders are not any more the only owners of the business, but as the firms operate in the society, they are responsible to it, and so firms are changing to be more accountable to all stakeholders. It also implies that the external environment – who gets affected by the activities of the firm – is concerned about such activities as the owners of the firm. Moreover, there are a number of stakeholders who have credible concerns regarding activities of a firm and the business activities impacts on them. They have both an interest and also an influence on the formation of the activities of a firm. Their influence is so substantial that, one can discuss that, the power of these stakeholders is as a kind of quasi-ownership of the firm. The traditional role of accounting in reporting results was challenged by Gray (1992) and Gray, Owen & Maunders (1987), who presented the view that what is required is a stakeholder rather than ownership approach towards accountability. This view has become more pronounced recently (e.g. Van der Laan et al., 2008; Mitchell et al., 2015) as shareholders are usually concerned with profits and dividends only, while stakeholders take into account the negative and positive externalities generated by a business as well (see for example Hutton, 1997, Sternberg, 1997 and Freedman & Reed, 1983). Additionally, writers such as Rubenstein (1992), Kakabadse et al. (2005) and Wilburn & Wilburn (2011) went one step ahead, and emphasized on the need of formulation of social contract between businesses and stakeholders.

The social contract between business and society has been revived in recent decades (Donaldson & Dunfee, 1994). The main concern of this social contract is for the future, and the use of the term “sustainability” is a manifestation of it (Seifi & Crowther, 2012). Such a term appears everywhere, either in the discourse of a company’s performance or in that of globalisation. Indeed, sustainability is a controversial issue for which, there are so many definitions about what might mean by it (e.g. Toman, 1992; Vos, 2007). The widest definitions of the term are concerned about the impact of present actions upon the available options in future, and this is central to the Brundtland definition of sustainable development (WCED, 1987). By using the resources now, nothing will remain to be used tomorrow, which is especially important if the amount of such resources is finite. Therefore, the quantity of extractive resources like oil, lead, iron or coal is finite, and as they are used, there will not be any available for later utilisation. In other words, those resources become depleted – a central

concern for this thesis.

2.8 Manufacturing firms and resource depletion

As resources become scarcer, then it is to be expected that price will rise, which will have the effect of causing more of the scarce good to be produced. For mineral resources, this can be interpreted that harder to extract reserves will need to be exploited. Farzin (2001) shows this to be true with oil reserves, and Arezki et al. (2014) shows this with respect to fracking activity. Conversely, Reynolds (1999) argues that price decreases due to improved technology coupled with reduced demand does not mean that scarcity is disappearing. However, global exhaustion of reserves of any mineral does not appear to be recognised, or at least to be recognised sufficiently for any action to be taken.

Despite any lack of concern over depletion and impending scarcity, it is apparent that costs of acquisition are increasing (Hatayama & Tahara, 2015). There is also evidence of stockpiling of scarce minerals at a national level (Erdmann & Graefel, 2011), but no apparent evidence among individual companies. Consequently, as scarcity becomes apparent, there will be competition for their acquisition, which will increase their price and the transaction costs of their acquisition.

2.8.1 Transaction Cost Theory

The Theory of the Firm (Coase, 1937) was developed in order to explain why firms come into existence, and the role of accounting in firms extended from providing accountability (an accounting) to investors to become a tool to aid rational decision-making. However, it does not explain the workings of a firm sufficiently. Thus, the role of accounting within a firm cannot be considered without a consideration of the people involved in that firm. The main people involved in the control of a firm are, of course, its managers, and Williamson (1970) argues that because in any large organisation the management of the firm is normally divorced from its ownership, then this is a factor which hinders its control and decision-making. This leads to internal inefficiencies within the firm and conflicts of interests, which mean that organisations do not operate efficiently as a means of transaction cost minimisation and value creating maximisation. From this analysis, Williamson (1970; 1975) developed what is known as the Organisational Failure Framework, describing how increasing size led to inefficiencies.

According to some (e.g. Scapens, 1994; Crowther & Hosking, 2005), when the activities of a company are concerned, then it can be considered that accounting adopts an internal perspective only, and does not recognise that some of the effects of the actions of the company have effects elsewhere; indeed, these are not considered to be relevant to the company which is operating under the assumptions of Classical Liberalism (Ruggie, 1982). The point is that accounting is used as a basis for decision-making within the firm, but as it does not record all information, then the best decisions may not necessarily be taken (Cohen, Pant & Sharp, 2001). It is standard financial theory that decisions need to be made based upon maximising the benefit, derived from the scarcest inputs into production. Most often, this is taken to be the capital involved in the process. Indeed, the theory of throughput accounting has been developed specifically to achieve this (Dugdale & Colwyn Jones, 1998). Moreover, the theory of constraints has also been developed to facilitate this end (Rahman, 1998). Although these theories have been subject to some criticism (e.g. Souren, Ahn & Schmitz, 2005), they have been largely accepted. This benefit is calculated and decided upon, using the accounting information available – as accounting is regarded as the language of business (Belkaoui, 1978; Bloomfield, 2008).

The salient point here is that finance does not necessarily recognise what is the scarce resource, but only what is relatively the most expensive being used. It has been argued (Reynolds, 1999; Gleich et al., 2013) that price and scarcity of mineral resources are not necessarily positively correlated. Therefore, this can lead to decisions being made, which do not reflect the best use of materials within the transformation process (Bacharach, Bamberger & Sonnenstuhl, 1996). Moreover, as mineral resources are finite and become depleted, then optimising their use becomes critical. Currently, that is decided by the firm according to their objectives, which will, of course, include profitability. Of course, governments interfere in the production decisions for various purposes – which are often military or strategic, but also for development reasons (Pack & Westphal, 1986).

There is no evidence of interference because of scarcity, although this might occur in future. It is important to acknowledge that mineral resources are finite, and therefore, the need to make best use of them is paramount. This is becoming recognised by such bodies as the US government (Rogich & Matos, 2008). There is also some consideration of mineral extraction and sustainability (e.g. Behrens et al., 2007), but this seems confined to a consideration of environmental effects.

The theory of firm is improved by the introduction of transaction cost theory. The core of this theory is that transactions are involved at every production process carried out by a firm, no matter if activities are carried out internally or externally. According to this, the best decisions are able to be made based upon the accounting information regarding costs and value creation. This enables the strategic decisions of the firm to be made based upon an understanding of the transformation process (Okumus, 2003). But this assumes that the accounting information provides the best information to make that decision. Hosking & Crowther (2009) argue that accounting information are not enough to decide on resource allocation based on transaction costs related to every transaction throughout the process of transformation. Hence, the basis of these decisions is incomplete information, and it is not possible for firms to accomplish the goal of optimal resource allocation.

2.8.2 The market and its inefficiencies

It is generally accepted, in economic theory, that the market is the place where exchange takes place either among individuals or organizations (see Keynes, 1937; Gomez-Baggethun et al., 2010). In marketplace, there is one party – which offers goods or services – and another party – which provides money for the purchase of these goods or services. The market is where these transactions take place in.

The way in which supply and demand are brought into equilibrium is through price. The implicit assumption – while describing equilibrium of any of these markets – is that all individuals act rationally and attempt to maximize utility. Moreover, in the long run, laissez-faire forces of demand and supply are the core of price mechanism. According to the free market theorists (Miller, 1962) and espoused by such people as Friedman and Johnson (1991), there is no need to intervene in the market, and the demand and supply forces should be let free to bring market in equilibrium and determine price. However, as Debreu (1972) argues, these factors only apply, if perfect competition is present, but the fact is that such a kind of competition never exists in practice. Ashford (2010) argues that the whole concept is flawed, and will inevitably concentrate wealth in a small number of hands. In practice, this market is influenced by the power of different actors: government regulation, the decisions of the company itself, and also, the expectations about the future and the present time. Hence, one can argue that existence of equilibrium price is not realistic, and even if there is an equilibrium price, it does not last for a long time.

However, one of the basic assumptions that equilibrium is a natural state, can be seen not to apply, and this is the basic problem with market efficiency and the price mechanism for transaction mediation (Buiter, 2002). However, the actions of the firm – in determining its operational processes and seeking to minimise its transaction costs – depend upon a stable equilibrium in the market, in order to make the necessary planning for operational activities. Therefore, it follows that as far as the allocation of resources for the minimisation of transaction costs is concerned, the market is also problematical.

However, it is generally accepted that by free markets, economic growth (Borts & Stein, 1964; Baumol, 2002; 2004; Porter, 2010) will be higher, which will benefit everybody. Although some have argued (e.g. Koedijk & Kremers, 1996) for the benefits of economic growth without regulation, others (e.g. Jalilian, Kirkpatrick & Parker, 2007) have argued that limiting economic activities of the world through market regulation is good for the welfare of people. The evidence is conflicting, which makes it a subject of continuing debate, and also means that one can find the evidence one looks for!
In order to provide perfect liberty for economic actions, regulations have been relaxed by governments. Therefore, such a worldwide marketplace has relaxed regulations increasingly for the global companies. This has resulted in some problems, probably the best known one being the collapse of Enron (see for example Vinten, 2002; Arnold & de Lange, 2004; Tourish & Vatcha, 2005), and the subsequent failure of Arthur Andersen (see for example Blouin, Grein & Rountree, 2007; Gendron & Spira, 2010).

It is important to bear in mind that the concept of the free market is based on the classical theory of liberal economy – subsequently developed into Utilitarianism and the foundation of the capitalist economic system. According to the arguments of people like John Stuart Mill (1863), Utilitariansim argues that so long as the outcomes are satisfactory, then everything is fine. Many, including Buckminster Fuller (1981) and O'Brien (2010) have argued that the regulation of accounting has altered from safeguarding the interests of owners and society, to focus upon solely business interests. This, in part, explains why any concern for the environment and the depletion of resources is missing from the discourse of business concern.

Howsoever the market and its operations are described, the fact remains that financial information (primarily price) remains the guiding force, with the assumption that this will enable an equilibrium to occur between supply and demand. This has worked fine for the

economic system of the world, but it assumes that price will always ensure that supply and demand align. In other words, there is an assumption for the mineral reserves of the world that increasing difficulty in extraction will cause an increase in price, which will lead to an increase in supply and a reduction in demand, enabling equilibrium to be maintained. However, once a mineral is fully utilised, the supply drops to zero, and it does not matter what happens to price, as any demand cannot be supplied. This, of course, leads to measures such as seeking alternatives and recycling (see Prior et al., 2012), but it is questionable whether this will be able to satisfy demand. It is also convenient to refer to the unknown quantities available in such locations as Antarctica (Cullen, 1994) and under the oceans (Rona, 2003), although Hibbard (1968) made the point that these too are finite.

It can be argued that when resources are finite in availability, and also scarce, then the pricing mechanism based upon the equalizing of supply and demand may not lead to the best result. One obvious implication is that rich people or countries, are able to acquire adequate supply, while poorer are not. This works according to the economic system, but does not either lead to equity or satisfy the expectations of natural justice. As such, therefore, it is unlikely to be sustainable and will lead to conflict. Therefore, an alternative needs to be considered to equate supply with demand. One such alternative is the concept of utility, which would need to be applied on a global basis.

This is problematic, despite Rouge & Karouli (2001) defining a model to relate utility to the price function. In general, all concern with utility has been in terms of the economic behaviour of the firm, rather than in creating the greatest possible global utility. Baron (1970) provides one example of such concern. For global economic utility maximisation, there has been little research of specific aspects. Thus, Gros (2009) considers implications of a carbon tax, while Coast (2004) considers the relationship between economic value and welfare. Roemer & Silvestre (1993) consider utility as a way of dividing resources between public and private sectors; however, there does not seem to be any research, regarding economic utility as an alternative to pricing for resource allocation. Given the lack of recognition of impending scarcity of mineral resources, it is, probably, unsurprising that such issues are not being considered.

2.9 Critiquing sustainability

It is apparent, from the analysis already undertaken, that a number of factors have combined to raise a general concern about sustainability, and to raise it to its current prominence. When this is combined with a recognition of the finite supply of minerals and increasing consumption, then there is clearly a need for conservation. Actually, the ability to achieve sustainability must be questioned, because resources are depleted, and so, we cannot preserve unchanged the options for the future as per the Bruntland definition. This is reflected in business approaches. Thus, corporate reporting into sustainability practices has been based upon a general adoption of the triple bottom line as a mechanism for measuring effectiveness. However, this has been heavily criticised, and Hubbard (2009) suggests a balanced scorecard approach as a more effective alternative. Conversely, Isil & Hernke (2017) criticise the approaches underlying assumption that firm level sustainability is actually achievable.

There are many definitions of sustainability, and many claims about what comprises sustainability. For followers of Brundtland, it revolves around not diminishing choices available for future generations (WCED, 1987), but with finite quantities of minerals available and their depletion, those choices must inevitably be reduced, or at best changed. Sustainability, in this context, would mean that society would use no more resources than it is able to regenerate (Aras & Crowther, 2008a), but minerals cannot be regenerated, and so, this is not an option. Instead, best use of them must be sought. There are various ways to achieve this, and Henckens et al. (2016b) argue for an international agreement on the sustainable use of mineral resources. Similarly, Henckens et al. (2016b) state that the price mechanism of the free market system will no longer work. Ali et al. (2017) argue that the supply of minerals requires some form of governance in order to ensure sustainability.

Research into the way in which manufacturing firms react to environmental considerations shows mixed results. Thus, Crowe & Brennan (2007) show very little concern among firms, while Agarwala (2005) argues the need for a strategic response through a recognition of a business and environmental interdependence. Ekins (1998) argues that there is a need for modification to the rules of world trade in order to bring about environmental protection. Wassmer, Paquin & Sharma (2014) find an increasing concern for environmental effects, but a mixed reaction to this awareness. None show any response to depletion of minerals in the world.

It can be seen that the concept of sustainability is problematic, and there is a further confusion surrounding its meaning: for some people, sustainability means nothing more than the ability to continue without change, but it is often interpreted as growth in a sustainable manner (for instance, see Marsden, 2000; Hart & Milstein, 2003). In fact, sustainability and sustainable development are considered to be synonymous for many people. When it comes to concept of corporate sustainability (Marrewijk, 2003), confusion is made worse by the fact that in the literature of management, the idea of being sustainable has been used for over three decades (as an instance, see Reed & DeFillippi, 1990) to promote the idea of continuity. This enabled Zwetsloot (2003) to merge the idea of corporate social responsibility with the development of techniques, which ensure steady continuation in improvement and development, thus to suggest that sustainability is ensured.

There is an almost undisputed assumption that growth is still possible (Elliott, 2005) – this is, indeed, one of the foundations of the Brundtland Report; consequently, sustainability and sustainable development can be treated alike. The viewpoint of market driven economics is universal, and means that development is not only possible, but also desired (Spangenberg, 2004). Under this assumption, Daly (1992) states that the economics of growth is all that must be dealt with, and that it can be achieved in the market by dealing separately with the three economic objectives of the efficient allocation of resources, sustainable scale, and equitable distribution of resources. This debate is continued by Hart (1997), who considers the idea of sustainable development, simply, as an opportunity for business. He further argues that, once a firm recognises its strategy towards the environment, then prospects for new services and products become obvious.

2.10 Strategies for dealing with resource depletion

In considering any strategies adopted for dealing with the depletion and impending scarcity of resources, it is necessary to investigate this at several levels: at the level of the firm, at the level of countries; at a global level. It is to this that we now turn, and the first point to make is whether there is any response to impending depletion of resources.

2.10.1 The level of the firm

There is no evidence that firms are reacting to expected depletions of mineral availability, although there is evidence of general reaction to possible shortages. Rosenau-Tornow et al. (2009) argue that market price is the most reliable way of determining expected shortages. However, Luiz & Ruplal (2013) argue that mining companies have recognised that access to available resources is possibly limited, so they have been acquiring such resources in Africa to ensure continuity of mining resources. However, they identify the reasons for doing so solely in terms of political instability and infrastructure weaknesses – rather than any mention of depletion. Hamann (2003) argues that such investment is a key to sustainable development, and extends beyond simply ensuring supply line; for him, this sustainable development is related to assisting the local communities affected by any mining.

2.10.1.1 The national level

Dasgupta & Stiglitz (1981) demonstrate mathematically that uncertainty, regarding the future availability of natural resources, enhances the rate of technological development, suggesting that this will alleviate any problems in future supply. As Amba-Rao (1993) states it is generally agreed increasingly that countries and companies should accept responsibility for enhancing people's interest in economic activities, and also for welfare of the society. Tilton et al. (2018) state that depletion is a very rare event, and that public policy should rely on signalling by market price that there may be a problem before taking action. Kim et al. (1989) recognise the need to adapt to resource depletion, and develop this into a model for dealing with groundwater shortages. There does not seem to be any recognition of the need to deal with mineral depletion, although the EU have a policy for dealing with shortages of raw materials (Blengini et al., 2017): this is mostly concerned with trade barriers and disputes, but it does consider strategies such as recycling. Similarly, Hatayama & Tahara (2018) consider supply disruption to minerals supply, but only consider this in terms of geopolitical factors and natural disasters.

However, world shortage is recognised in some arena, and Burgess & Beilstein (2013) point out that China is aware of critical shortages of some minerals, and has sought to acquire and control access to them. However, they argue that global forces will ensure that flows of such materials around the world will continue, although they also argue that the USA has the power to stop any flows of materials.

2.10.1.2 The global level

At this level, Rosenberg (1973) states that adaptive measures – presumably technological advances – will resolve all problems. This is, of course, a simple restatement of the Brundtland standpoint. More recently, Krautkraemer (2005) states that there has been a focus upon ecological resources, but that technological progress has made any scarcity of mineral resources to become an insignificant problem – no change in 40 years! Similarly, Gordon, Bertram & Graedel (2007) state that geological data is too scarce to accurately quantify any problems, but that evidence suggests that increased recycling together with the development of alternative materials show that there is not a problem. This is a response to Tilton & Lagos (2007), who suggested that there may be a scarcity of copper resources before the end of this century. Diederen (2009) argues that many metals will soon become scarce, which will affect their extraction rate. He argues that we cannot rely on technological breakthroughs to solve all problems, and therefore, proposes a global coordinated policy of "managed austerity", relating their future use to needs rather than luxuries. However, this is only an opinion piece.

2.10.2 Stockpiling

Businesses have always had a policy of stockpiling raw materials to compensate for supply irregularities, and to smooth production of their own products. This is regarded as normal behaviour and good business practice. Governments also have system of stockpiling of what they regard as critical materials, to overcome temporary shortages caused by disruptions in the supply chain, such as political unrest, trade disputes, etc. Thus, the EU has a policy regarding such minerals as rare earth minerals (Gardner & Colwill, 2016). Such practice is long established, and Huddle (1976) analyses the US policy in this regard, showing that it was extending beyond its origin in defence preparations and into manufacturing needs. Indeed, Gloser et al. (2015) show that this takes place within the context of risk assessment on an ongoing basis.

There is no evidence that firms or governments are reacting to mineral depletion in any way. The consensus seems to be that any shortage is not imminent, and will be overcome through the pricing mechanism and through technological advances. Given that there is no significant acceptance of any impending shortage of minerals, this is probably unsurprising. Thus, any actions currently being undertaken are only concerned with expected shortages due to supply

chain difficulties, trade disputes, political disturbances and environmental factors. As there is an expectation that technological changes will solve any mineral shortages, it is to this aspect that we now turn. All strategic planning is related to these ends only.

2.11 Technological solutions

As already discussed, there is an expectation that technological change will be able to overcome any problems from mineral depletion (see, for example, Prior et al., 2012), although this is not universally accepted. Indeed, the general view does not seem to have changed since Tilton (2003) pointed out that there were mixed views and the reality was unknown. Nevertheless, technological change is taking place regardless (see, for example, Kayal, 1999); some has an effect upon minerals usage, and some is related to better mining or production methods. Nevertheless, Levinthal (1998) describes change as punctuated in a Lamarckian[26] sense (Massey, 1999).

Some such change is considered to have a very great effect on mineral depletion through its effect upon sustainability, although developed primarily for cost reasons. Examples include the development of the production of hydro-electricity and its use of a constant source of power, i.e. water. Another example would be the development of plastic as a substitute for metals, in manufacturing and in packaging, and even as a substitute for natural products in the manufacture of clothing. A further example would be the use of asbestos as a substitute for other building materials. There is always a danger, though, of unintended consequences from such technological developments which become apparent in the longer term.

Hydro electricity was used as a cheap commercial substitute for fossil fuels, but had the advantage of being a clean and renewable source of electricity (Sims, Rogner & Gregory, 2003), although many have become less certain of the environmental benefits of such renewable energy (Raadal et al., 2011). Other problems are less apparent, such as geopolitical tensions when rivers flow through more than one country (see, for example, Maganda, 2005). Of greater significance for considerations of sustainability is the environmental damage caused

[26] Jean-Baptiste Lamarck (1744-1829) created the first theory of evolution in which he argued that organisms increased in complexity while also adapting to environmental factors. This became known as punctuated equilibrium in which evolution was not gradual but static and subject to incremental changes. This theory is still considered to be as valid as the better known Darwinian theory.

by damming rivers. This is, particularly, manifest in river deltas, which has significant effects upon the animals and plants living in the delta and in the lakes created by the river control process. This kind of damage to the environment is only recently recognised (see, for example, Poff & Schmidt, 2016; Anon (b), 2019)[27], although social and environmental effects have been recognised for some time – see, for example, Rosenberg, McCully & Pringle (2000); Imhof & Lanza (2010).

Plastic has long been used as a substitute for other materials in manufacturing (e.g. Cochran, 1988), in packaging (e.g. Lange & Wyser, 2003), in clothing, in medicine (e.g. Chung et al., 2009), or in combination with other materials (e.g. Sourey et al., 2009). It has been used for many reasons, including better performance and durability, but also, for its cost savings. However, it is currently a major problem, as much cannot be recycled and is not biodegradable. So, the planet is becoming littered with discarded and unwanted plastics, which is threatening the environment (Moore, 2008), as well as human life.

Asbestos was first used as a substitute building material at the end of the 19th century, but by the 1960s, it had been discovered that there was a firm link between exposure to asbestos and the acquisition of lung problems, which became known as asbestosis (Selikoff, Chung & Hammond, 1964; Hammond, Selikoff & Seidman, 1979). The use of asbestos was gradually banned after this.

Therefore, it can be seen that substitutes for scarce minerals can be problematic, as there can be problems as well as benefits in such substitutions. This problem is exacerbated, as it is apparent that the benefits accrue in the short-term, while the problems may only become apparent in the longer term. Thus, problems may manifest in the future, which contravene the definition of sustainable development, which expects choices made in the present to not limit choices made in the future. Naturally, delayed understandings of problems will also change the cost-benefit calculus of using such substitutes. Therefore, it can be seen that the assumptions made that technological changes will take care of any future shortages, may not necessarily be true. It also ignores the moral dilemma of leaving problems, created in the present, to be solved by future generations. Therefore, it seems that strategies for addressing this problem have not been developed, presumably because any impending problem is not recognised.

[27] https://www.internationalrivers.org/environmental-impacts-of-dams accessed 5 June 2019

2.12 Free market economics

It still seems to be assumed that the market will take care of these problems, as they become apparent, presumably, through the working of the pricing system. The contemporary world works under a simple economic model which is free market and, by its operation, both, ensures optimal distribution and also maximises economic wealth (Donaldson, 2001; Crowther & Mraovic, 2006). One key assumption within this model is that regulation reduces the efficiency of the market and limits growth and development. This is one of the founding beliefs of the Chicago School of Economics (Fogel, 1966), who developed Trickle Down Theory for its legitimation. However, there is no evidence of the existence of the features of this theory (Arndt, 1983).

Thus, governments everywhere in the world are under pressure to eliminate – or at least significantly reduce – regulation so that each segment of the society can take advantage of the prosperity which results because of the free market. An aspect which is not discussed is that a totally unregulated – or free – market functions effectively, only in case of perfect competition[28], which means never; in other words, the free market will not be effective in the absence of perfect competition, that gives multiple choices and alternatives to consumers. Of course, a perfect market cannot exist (Hayek, 1946, 2016; Klein, 2016) and it remains an ideal used for preliminary teaching only. Currently, any plan for globalization formulated by organisations like World Trade Organisation is on the basis of no national regulation, with companies undertaking their social responsibility completely voluntarily. Thus, outcomes are based on profits, without regard for any social responsibilities. Perhaps surprisingly (considering the discussions among politicians and the press), the problems of 2007 onwards, concerning the financial and economic recession – widely attributed to failures in the banking and financial system – did not lead to any changes (Verick & Islam, 2010), and the unregulated free market is what is desired, and increasingly exists.

When it comes to business activities of a firm, the control systems and management follow a completely internal viewpoint, and fail to identify that the impacts of the activities of the company have influences exterior to the organization. If assumptions of Classical Liberalism

[28] It is an initial assumption in the elementary economics that is soon abandoned. Although it is just a theoretical assumption, deregulation is justified according to it.

are taken into account, these influences will all become unrelated to the company. Additionally, the way of calculating costs, as performed by companies, is on the basis of the service or product that the company offers, as the basic unit of cost.

The situation is explained through Transaction Cost theory (Williamson, 1975) by giving a description of the transformational process, and it assumes that every activity of the company is a transaction. It does not matter whether these transactions take place within the firm or externally – these are just two forms of the market (Geyskens, Steenkamp & Kumar, 2006). These transactions provide a basis for undertaking exchange by attaching a cost – and therefore, a price – to the transaction (and price justification is an integral part of the economic system).

It will be apparent that as resources become scarcer through depletion, then the transaction costs of acquiring them will increase. These transaction costs relate to the costs of extracting the resources from the earth as well as the costs of arranging for them to be acquired and delivered to where they are needed. In other words, resource depletion leads to a scarcity of these raw materials, while development leads to an increasing demand for them. Thus, transaction costs can be expected to increase over time in the current environment, as firms compete for ever more scarce resources. Therefore, in this context it can clearly be seen that the scarce resources are environmental resources rather than the financial resources – which theory assumes and is based upon. As business activity is based upon securing maximum benefit from the scarce resources of the business activities, then this has implications for economic activity.

It is clear, of course, that firms are constantly in a process of changing of the source of their transactions through their activities, and at all times are involved in integration and divestment. Therefore, it seems reasonable to assume that the managers in such firms realise their costs of transactions and react to them. Possibly surprisingly, Williamson (1970; 1975), through his "organisational failure framework" (OFF), argues the opposite, and states that this will not happen in an efficient manner, because of distortions in communication and also bureaucracy.

This theory of organizational failure (OFF) explains why there are problems with firms, especially, as they increase in size. Thus, they are not efficient allocators of resources, and the alternative is allocation through the market as external to the firm. However, markets themselves do not operate efficiently, and the idea of the perfect market based upon perfect

knowledge has been adequately debunked by the 2007 recession and its aftermath. Thus, price itself is deficient as a mechanism for resources allocation, and intervention of some form is required. This leads to a need for some form of governance and regulation, to ensure that resource allocation can be undertaken in an efficient and optimal way. It is to this issue that attention is now turned.

2.12.1 Dealing with market and resource allocation inefficiencies

As has been described above, the emphasis of economic theory is on market as a place for exchanging among various people or firms. Here, the market provides a means of exchange which determines the costs of undertaking the transactions, with price being the mediating mechanism. This is explained by the theory of the firm (See Coase, 1937), and by transaction cost theory.

An examination of the theory of transaction cost depicts that there are several reasons for which, companies fail in making optimal decisions. This concept can be applied to all circumstances, and holds similarly even in case where Game theory depicts what the optimal strategy is (Shapiro, 1989; Levy, 1994). Such a failure to make optimal decisions in every case is a characteristic of any firm, and holds even when an organisation is striving to make the best decisions which make the most of the outcomes to that organization. It has been observed (Ortiz-de-Mandojana & Bansal, 2016) that there is difference between the long-term and short-term benefit for a firm. In a similar way, it is also evident that market, as a mechanism for resource allocation, does not perform perfectly, and hence, sub-optimality is acknowledged (Brynjolsson, Dick & Smith, 2010). The recent financial crisis of 2008 onwards illustrates this vividly. In a world in which resources are over-exploited and are decreasing in supply, it is necessary to find a solution. However, a part of such a solution might need political actions which are not relevant to this research, where the attention is on sustainability. However, imperfections in market and necessity of best solutions for the world require a type of mediation, which is the role of governance. Gereffi, Humphrey & Sturgeon (2005) consider the governance of global supply chains, and argue that it is complex and varies widely. They argue that various types of governance chains can be identified, but that they are all based in transaction costs economics, and depend upon the level of power asymmetry between the actors.

It has been identified (Hartley, 2005; Crowther, 2009) that governance is primarily a top down process which is determined by those in power and implemented for all society. However, the process is originally a democratic and consensual one, as it is simply a kind of process through which a number of people choose to sort out their problems and connect together. Anyhow, this type of consensus is only manageable for the very limited groups of people, and in fact, no country has been able to set up governance by consensus. The present supranational bodies[29] even make its happening look less possible, or even not desired. Therefore, through an enforced hierarchical governance, the society would adopt leadership, and would be able to make such kinds of decisions that otherwise they would not be able to[30]. At the same time, it will let power to be forced on people in a dictatorial manner. Even if this is beneficial to the society[31], but it is unlikely that many people would be interested in this. Thus, it can be seen that systems of governance can only continue if they are based on some degree (although perhaps minimally) of consent – or its alternative of coercion. In chapter 6, the implication of this are considered in the context of the research undertaken in chapters 4 & 5.

2.12.2 The concept of global governance

All governance systems are mainly concerned with management or governance of formal groupings of people (Mallin, 2004), and hence, with political power, institutions, and eventually control. In this context, the idea of governance denotes official political institutions, which are aimed at coordinating and controlling interdependent social associations and can implement decisions. In the modern world, the idea of governance is commonly used to explain the regulation of interrelated associations, given the nonexistence of any overarching political organisation, like that of the international system (Jessop, 2011). Hence, it can be suggested that global governance means managing the world processes when there is no government for the whole world. At the moment, organisations such as WTO and UN address such issues. Arguably, the G20 does so also, although its interests tend to be more political than environmental. Such organizations have accomplished partial success in introducing some kind of world governance. However, as Rosenau (1999) suggests, these organizations are a part of acknowledgment of the complexities and an effort to address international problems which exceed the ability of countries to solve.

[29] For instance, like the European Community or the World Trade Organisation.
[30] As an instance, invasion to Iraq in 2003, probably, was not decided by agreement.
[31] Beneficial dictatorship to run the city states was favoured by the ancient Greeks.

By mentioning global governance, there is no implication that such a system actually exists (as it plainly does not). Equally, any study of the effectiveness of such a system is not claimed to exist. Instead, it is just to acknowledge in a world heading toward globalisation that sorting out problems in global and international levels requires a kind of governance. Hence, this is a descriptive expression, which is to acknowledge the problem and address the arrangements for collaboration to solve problems (Lobel, 2004). Such arrangements might consist of laws or formal organisations to deal with matters of collective interest of such bodies as NGOs and intergovernmental bodies, countries, as well as private sector bodies and pressure groups. Governance, at this level, is central to the problem of this research, and will be discussed in next chapters. Such a system incorporates both formal (such as coalitions) and informal (such as guidelines and practices) units, as well as the temporary ones. Hence, it can be suggested that, a world governance is a combination of informal and formal institutions, associations, processes and mechanisms among citizens, intergovernmental and nongovernmental organisations, markets and countries to articulate matters of common interest, mediate the differences, and to establish obligations.

It is important to stress that, global governance cannot be defined as world government (Castells, 2005). In fact, if the world had a unique government, then there would not have been any need to such a system. But today, the enforcement power is the lawful monopoly of different governments. Hence, by global governance, it means an interaction between different countries in order to sort out issues affecting several countries or regions, when compliance cannot be enforced. Indeed, enhancement of solving global problems does not need setting up stronger formal institutions. Instead, what is needed is existence of consensus on standards and procedures to be followed.

It can be considered that steps are currently in hand to form a consensus, such as the creation of means for global accountability. For instance, the UN Global Compact[32], which has been labelled as the biggest voluntary corporate responsibility initiative of the world, comprises the views of international and national bodies, businesses, labour unions and different NGOs to protect the principles of environmental conservation and also human rights (Ruggie, 2002). There is no enforcement of the principles by anyone and participation is completely voluntary. Increasingly, however, companies adopt the Compact because they are economic-wise

[32] See www.unglobalcompact.org

sensible, and also as their stakeholders, including their shareholders care increasingly about these issues. Therefore, it provides a means to enable the monitoring of compliance by companies. Such techniques as the Global Compact increase the power of local communities, and also individuals, to make companies keep accountable.

The importance of good governance is imperative in all parts of society; not just in the corporate environment, but also the political environment and society generally (Kell, 2005). For instance, improved public confidence in the political environment stems from strong governance. When the economic situation means that resources are limited and people cannot meet their lowest expectations, then good levels of governance can help to satisfy people and promote the general welfare of society. Naturally, a firm's concern with governance is also very important in the corporate world.

An essential factor for good performance of a company is good governance (Bhagat & Bolton, 2008), and an aspect of it is stewardship (Donaldson & Davis, 1991). In the context of sustainability, it is reasonable to argue that the concern of a firm's manager would be equally about the stewardship of the firm's environmental resources, as well as their financial resources. But environmental resources are different, because they are often situated outside the firm. So, in this regard, such stewardship should be concerned with the firm's as well as the society's resources. Then, it can be concluded that the stewardship of the outside environmental resources should involve the provision of sustainability. Predominantly, sustainability has a focus on tomorrow, and concerns about making sure that the options made regarding the consumption of resources at present do not unduly limit the choices available in the future. This includes a range of activities, such as the reduction of waste, minimising pollution, and generating renewable resources (or finding alternatives). It also includes the development of new techniques through research and development. Besides, sustainability requires an acceptance that current investment is partly an investment for the future, and not merely a cost to be borne (Lo & Sheu, 2007).

It is standard within economic theory that the environment, in which economic activity takes place, is based within a free market with open competition. This is because it is generally accepted that competition engenders the necessary incentives for, both, efficiency in operations and equity in the way in which benefits are derived and shared. It is only when the market itself seems unable to ensure such features that government intervention becomes necessary. It has

been argued (Kane, 1991; Crowther & Seifi, 2011; Jessop, 2011) that the resulting regulation is a means of replacing the imperfectly operating market forces, and acts as a substitute. The point of this intervention through regulation is to make sure that nobody is in a position to exploit the inequalities in power in order to gain benefits. It is also to make certain that the gains in efficiency result in equity in the distribution of the resultant benefits

One form of regulation – which has been generally used – is that of self-regulation, in which an industry controls the activities of its own members, and this has been generally accepted as satisfactory. It has more recently been shown that such self-regulation (Evetts, 2002) does not operate satisfactorily, as the Enron debacle showed with respect to the auditing industry and the demise of Arthur Anderson. In such cases, it is clear that external regulation is required (Veljanovski, 1991). Crowther (1996) argues that the purpose of such regulation is to balance the needs of the various stakeholders, which each tend to have a different perspectives and expectations, regarding satisfactory performance of the company concerned and the distribution of benefits; however, mostly two groups of stakeholders are paramount – customers and investors.

The focus in the western capitalist countries is highly on returns provided for the shareholders, which makes them the most important stakeholders. It has been argued (Crowther, Cooper & Carter, 2001a; 2001b) that the duty of the regulators in the countries governed by regulation has been to safeguard consumers, so that monopoly would not abuse their rights. When discussing about customers, then the main focus is on the local ones, perhaps because their number is the highest, and they are in the poorest situation for bargaining, or perhaps as government needs their voting for elections. Regulation here is based upon the idea of protecting the consumer so that they would not be abused to the cost of shareholders. Therefore, National Consumer Council (1989) considers that shareholders are only allowed to receive higher returns, if prices are reduced for consumers. In the United Kingdom, such kind of regulation was common in the beginning of this century, and again it has become favourite, as it is argued that equitable distribution is impossible through other kinds of regulation.

During the 2008-13, financial crisis failures in regulation and governance was highlighted. As stated by Grabel (2003), there is one flaw in the argument surrounding such failures, and a problem about how to manage in order to prevent financial crisis in future. This is related to acknowledging and regulating a financial market which is truly worldwide. The consensus of governments has led to freedom of movement for funds around the world's financial markets,

which arguably led to a global crisis of 2007, through a disguising of doubtful debts within a variety of financial packages. One of the causes of the crisis was that these packages were not understood by anyone (The Economist, Sept 7 2013) and just accepted - in which case, this form of investing is no different to gambling such as Russian Roulette, and decries any claim of the efficient market hypothesis (Malkiel & Fama, 1970). Therefore, one conclusion to be drawn is that as Becker & Westbrook (1998) state, it is impossible to have a realistic kind of regulation. As a result of such failure in regulation, contamination migrates everywhere, and faulty processes used somewhere in financial markets changes to a norm for the whole of markets.

2.13 Summary of the analysis

It is clear that sustainability is an issue of considerable interest and concern, not just amongst researchers, but also among politicians and the general public. There is a general recognition that achieving sustainability will require some changes to lifestyle (e.g. Mont, Neuvonen & Lahteenoja, 2014), but there is no clarity about what those changes might be, nor how they might be achieved. However, it is assumed that some changes in patterns of consumption will be required (Spaargaren, 2011).

It is equally undisputed that the mineral resources of the planet are finite, and that there is no alternative sources, as exploitation of outer space has not progressed beyond speculation (see, for example, O'Leary, 1977). There has been some speculation about the extinction of mineral resources, but most researchers are more interested in showing that this will not happen in the immediate future (e.g. Weitzman, 1999; Prior et al., 2012). Additionally, it is suggested that technological changes will make minerals more available and commercially exploitable, while also suggesting that approaches such as recycling, repurposing, and the circular economy will also obviate any shortages – at least, in the immediate future. However, some researchers argue that extinction of certain minerals will happen later in this century. Thus, there is considerable uncertainty as to when lack of availability will become apparent – but there is a general acceptance that this will happen sometime in the future. The consensus is that there is no need to prepare for this eventuality, even though the preparation for lack of certain minerals could be a lengthy process.

Thus, there is no work done on how best to respond to ever diminishing supplies. It is assumed that the supply – demand relationship as mediated through price will take care of this, without any need for a consideration of alternatives. Such extinction studies, as have been carried out, have been related to species or geographic areas rather than the planet as a whole. Obviously, it is different to look at a geographical area when alternatives exist, than to look at the planet as a whole when no alternatives exist. Therefore, it is clear that a gap exists in the research, and into which this research will fit.

If the problem is not really recognised, then it is not surprising that alternative approaches to a solution have not been considered. Thus, any alternative to the pricing mechanism has not been considered, and problems of the governance and regulation of such an environment have not been considered. Thus again this suggests a clear gap in the research into which this thesis will fit. However, resource depletion is a real problem which will become more apparent in the future, as the world seeks further economic development while resources become harder to find. This thesis seeks to explore possible solutions to this problem so as to bridge the gap in literature. In order to do so, use is made of Game theory as a strategic decision-making tool. Next, therefore, it is necessary to consider this theory and its role in decision-making.

2.14 Game theory

Game theory is usually considered to be associated with the card game, which is not unreasonable, as it was devised to increase the winning chance within such card games. It was first introduced by Charles Waldegrave in 1713 (Bellhouse, 2007). In general, the players of cards were thought to be clever mathematicians, with higher problem-solving skills. Currently, the theory is known as a part of applied mathematics[33], which "attempts to mathematically capture behaviour in strategic situations – or games – in which an individual's success in making choices depends on the choices of others" (Myerson, 1991 p 1). Within the process of decision-making, there exist various risk factors that are necessarily required to be suitably treated for the expected result to be optimised. Furthermore, for many years, researchers have looked for ways to provide optimization of results. In addition, mathematical methods such as risk analysis and Bayes theorem have been used for effective optimisation of outcomes.

[33]Game theory did not exist as an explicit field until the publication of a paper by John von Neumann in 1928. Now, this field has larger number of Nobel Prize winners than any other economics branch.

However, if the need concerns strategic decisions, then Game theory is always the best approach.

For problem solving, then the simplest situation for which a problem can be solved is one in which there is a single decision-maker, and this is based in decision theory. Here, the purpose is to seek to maximise utility before any decision is made. It is possible to consider decision theory as the theory of one person games, or of games where the other player is simply nature, itself (Levine, 1998). We understand, though, that when the decision is concerned with the actions of a factory or a company, then this factory or company cannot be treated discretely as a black box. Although true in all circumstances, this is particularly so, when the external environment is affected by the decision; examples include when the company is about to institute the launch of a new product, or increase the prices charged, or going to start a marketing campaign (Marland, 2006). This situation requires much more than decision theory offers, because the company is not totally separate from its rivals – who may well react – or from the external atmosphere. In such a situation, more than decision theory is required to deal with the situation, and this is when Game theory becomes important.

2.15 Game theory and the process of decision-making

Throughout the decision-making process for the ensuring of sustainable production and consumption and associated governance, there are several parties involved. Thus, to effectively understand what is involved, we must first start with a review of the background to decision-making processes; afterwards, it is possible to choose what is needed for this particular case.

Game theory has been described by Dietz and Zhao (2011) as one of the most powerful tools which exist for truly understanding various common problems, including climate change. Thus, Game theory has been defined by Turocy and Stengel (2001) as the formal study of decision-making in situations where several players must make choices that potentially affect the interests of the other players. Therefore, it is essentially concerned with strategic decision-making, where each party can make decisions independently of other players, and where not all players may have complete information. This has been described by Schelling (1960) as devising strategies for dealing with conflict.

Over time, a number of forms of game have been included into Game theory: examples include zero-sum and non-zero sum games, symmetric and asymmetric, simultaneous and sequential, perfect information and non-perfect information, infinitely long, discrete and continuous, one-player and many player, and meta-games. Furthermore, various authors have tried to develop other theories, by which they can categorise these different sorts of game. Thus, Levine (1998) has described mechanism design theory as a different theory to Game theory, because it (Game theory) assumes the rules to be predetermined, whereas mechanism design theory starts by identifying the consequences of different types of rules. However, this differentiation has not been generally accepted; instead, several ways to present the game have been described, such as normal, extensive, characteristic function and partition function. Indeed, Game theory is clearly agreed to be a branch of applied mathematics (Buchanan, 2001), and has been utilised in many diverse fields such as physics, economics, politics, biology, business, computer science, and philosophy. It has proved particularly powerful in analysing situations concerning international politics (e.g. Snidal, 1985; Pahre & Papayoanou, 1987), but it is in the area of business decision-making (Brickley et al., 2000) that it is particularly relevant to this thesis.

2.15.1 Utility theory

Essentially, Game theory formulates strategic decisions so that they are subject to mathematical analysis, and this requires the transposing of events and outcomes into a numerical format. In business, this is frequently assumed to be financial numbers, but in Game theory, this is not necessary. Instead, outcomes can be quantified in terms of utility. Utility is a concept which was first formulated by the economist Alfred Marshall (1890) to represent a measure of personal preference, which might not be in financial terms, but rather in use value received. It is a representation of satisfaction, and is based upon the philosophical approach to satisfying individuals, known as Utilitarianism developed by John Stuart Mill (1863). It is a concept which is not without problems in considering regulation of markets (Schwartz, 1988; Crowther, 2011), and will be returned to later in the thesis.

Utility was adopted by Game theorists as a way of measuring outcomes, and was adapted by von Neumann & Morgernstern (1944) to be represented by probabilities, when precise outcomes were not known (or were multiple). Copeland (1945) describes this as replacing the marginal utility theory with something more useable, while Simon (1945) describes this as a significant advance. In effect, it means that all strategic problems can be mathematically

quantified (Piney, 2003) without precise knowledge of outcomes - as it is only relative preferences which are significant to most such decisions. In theory, the concept of utility enables all outcomes to be quantified for comparative purposes, but this is overly simplistic. For example, Markowitz (1955) showed that relative size of absolute values affected choices made, while Scodel, Minas & Ratoosh (1959) showed that choice is made according to the personal values of each individual subject, thus, demonstrating that utility is relative rather than absolute. Equally Luce & Raiffa (1957) showed that gambling took place depending upon perceived (and, therefore subjectively interpreted) odds. Many (e.g. Kainuma & Tawara, 2006; Kaplinski, 2013) have discussed applications within business. Thus, the concept of utility enables quantification of problems, but it is a mistake to assume that every person's choice of a rational outcome is identical.

2.16 Importance of Game theory for resource consumption

All business decisions are strategic decisions, and are games within the scope of Game theory. In other words, they are games of strategy (Williams, 1954) which can be formulated as problems to be solved. von Neumann & Morgenstern (1944) define them as problems of economics, and argued that economics was too simple to provide solutions to such problems, which is why they developed their mathematical approach. However, it must be remembered that in 1944, economists did not make use of mathematical modelling, and barely made use of calculus even. Nevertheless, von Neumann and Morgenstern made use of one aspect of economics - that of the assumption of rational decision-making.

Various techniques have been developed by von Neumann and Morgenstern, and by many others, in order to solve the games. These techniques have been used extensively, not only in business decision-making, but also in international politics and diplomacy (see Schelling, 1960; Poundstone, 1992; Bridge & Radford, 2014; Bjola & Manor, 2018), and in many other areas. However, the skill in solving games of strategy is not to be able to solve the games – solutions are often obvious, once the problem is formulated; rather, the skill lies in being able to formulate the problem, and depict it mathematically in Game theory terminology. Thus, problem identification is more important than problem solution – something which is often overlooked, but is significant for this thesis.

At this point and following the introduction to Game theory and definitions, it becomes imperative to explain why the theory is important for dealing with resource consumption, especially raw materials, as is the subject matter for this thesis. In this thesis, the intention is to use Game theory in order to show the path towards the preservation of the earth and an increase in sustainability, as well as to motivate businesses and states to act responsibly. According to Parkhe (1993), this is very related to transaction costs economics within the making of the strategic decision. Harstad & Liski (2013) argue that Game theory is the best tool to use when analysing the strategic use of resources, but really liken the analysis to a look at the tragedy of the commons. Song & Panayides (2002) show that the cooperative Game theory can be applied to the development of strategy by shipping companies. Dutta & Radner (2006) consider an approach to global warming by investigating the effects of the countries concerned. However, they neither really consider the benefits or otherwise to individuals, nor question that the current economic model may not provide solutions, as this thesis does.

The objective of such analysis is to use Game theory, in order to facilitate the major stakeholders in various states, to participate in a balanced manner in the development of sustainability strategies, towards minimising resource utilisation and combatting global warming, in order to preserve themselves without relying on other states to lead them. Of course, a change and slowing of global warming will lead to a reduction in resource consumption, just as reducing resource consumption will slow global warming – the two are inevitably interrelated. According to Dietz & Zhao (2011), international agreements have not had much success in making an impact on the concentration of greenhouse gases in the atmosphere and the steady increase in emissions. They attribute this to the difficulty in getting nations to sacrifice their own self-interest and to trust each other - a perennial problem in politics. Moreover, it should be recognised that the control of such emissions is not a great vote-winner, and so, it is not high on the priority list of any country.

If we apply Game theory, for example, for the case of the atmosphere, it can be readily demonstrated that, if one country incurs costs in reducing emissions from greenhouse gases whereas other countries do nothing, it will not greatly affect the reductions in risk of climate change, because no single country can make much difference (Bohm & Larsen, 1994). Greenhouse gases are, of course, all the gases that cause heat to be trapped within the atmosphere of the Earth. The principal greenhouse gases specified in the Kyoto Protocol are nitrous oxide, carbon dioxide, methane, and other industrial gases like sulphur hexafluoride,

hydro fluorocarbons and perfluorocarbons. Although greenhouse gases encompass six gases, but carbon dioxide is responsible for about 55 percent of them. Accordingly, greenhouse gas accounting is often called carbon accounting. Water vapour is also considerable, but much of it happens naturally in the atmosphere. Dietz & Zhao (2011) explain it by saying that in case other countries do not collaborate, as a result, it is my country which has incurred the total costs of reducing emissions, although it will not be at lower risk of climate change. In contrast, in case my country does not reduce its emissions while other countries do so, then my country will gain the benefits of reduced risks, together with no costs for reducing emissions. This will result in what is known as the tragedy of the commons, where every country has a motive to free ride and carry out insufficient or even no emission reduction, which will lead to great risks of climate warming for all of the countries. In case we take the assumption that all countries act rationally to their own benefit, then risks from climate change will be reduced by formulating some rules agreed by all the countries, as they will know that these rules are to their benefit.

A first significant international step towards reducing greenhouse gas emissions occurred when the Kyoto Protocol was accepted in 1992. In 1992, the "UN Framework Convention on Climate Change" was formulated and accepted by most developed countries. It was designed to set limits on the emissions of greenhouse gases, and so to minimise the negative effects of climate change. In 1997, the abovementioned convention formed its third meeting in Kyoto, Japan, the result of which was the Kyoto Protocol. In 2005, after it was agreed by 132 signatory countries to put their efforts for reducing carbon dioxide emissions, the Kyoto Protocol became very binding. The Kyoto Protocol sought a division of the participants into two groups of developed and developing countries as a measure of protection against global warming. As developed countries emit a great deal of greenhouse gases, they were committed to decrease their emissions of six greenhouse gases by 2012, minimum by 5.2 percent of the levels in 1990. Sadly, the plan was deferred and dropped – possibly because of a politically easier course of action, although Madani (2013) suggests a simplified Game theory model to provide policy insights about climate change, and hence, emissions. However, since then, the Paris Accord has been signed by almost all countries, although significantly, the USA under the presidency of Trump has withdrawn.

This Protocol sets out three mechanisms, which let the developed countries who have committed to reduce their emissions, to gain credits for green-house gas reductions. The three

mechanisms are Clean Development Mechanism, International Emission Trading, and Joint Implementation. The future of the Kyoto protocol appeared to be in doubt as the original agreement expired. It has been replaced by the Doha Amendment, but this has been signed by relatively few countries. Fortunately, the Paris agreement of 2015 has been adopted by the world and most countries, so we await any signs of this making an impact. Identifying a problem and agreeing a solution are not straightforward, and this applies to all issues of sustainability. One of the problems is concerned with policing any agreement at an international level (Vogel, 2011), an issue which will be returned to later in this thesis. Another issue is concerned with sanctions for non-compliance (Betsill & Bulkeley, 2006). However, Ciscar & Soria (2002) show that Game theory can be applied to the issue to seeks its resolution.

Punishments for non-compliance with targets of greenhouse gas emissions were considered to be important, but scientists have declared that these punishments can be very costly. Dietz & Zhao (2011) point out that if nations think that they would be punished due to failure in succeeding, then they might decide not to take part. Additionally, due to lack of certainty on some views about climate change, some countries might be reluctant to commit themselves to obligations about their emission targets and facing punishment in case of not meeting with them. Thus, sanctions are problematic and can lead to pressure to not participate, even though they can be considered to be necessary to ensure compliance to such agreements. Thus, the concept of international agreements in this area is problematic.

2.17 Previous use of Game theory for sustainability problem solving

Dealing with issue of sustainability is fairly new for business decision-making and is equally new in business mathematics. Thus, the theory is not previously much used for formulating problems concerning sustainability. Few examples of previous research in the field exist, but Madani (2010; 2011) has used Game theory to look at problems of water resources; his analysis has mainly considered the potential conflicts which might arise – so primarily a political analysis rather than a business decision-making. Similarly, Helm, Hepburn & Ruta (2012) have investigated carbon emissions and problems arising, while Zhao et al. (2012) have considered carbon trading, but again these have been primarily dealt with problems arising from these issues. More generally, it has been claimed by Vasile, Costea & Viciu (2012) that Game theory as an application is a general technique to consider the open market and its working, as well as

associated economic realities. These all support the application of Game theory to sustainability which is made in this thesis.

As far as resource depletion is concerned, this has only been investigated in a local context (see section 2.6) concerning animal behaviour and habitat. These studies are an aspect of the tragedy of the commons' analysis, and such scenarios do not apply at the global level when there is no alternative available. Other research has focused upon international borders and access to resources and the conflicts resulting access to borders therefrom (e.g. Le Billon, 2001). This is, of course, one of the principle applications of Game theory – dealing with conflicts at a strategic level (Hand, 1986). Much of this analysis focuses on geopolitics, either locally or globally. Interestingly, as already shown (section 2.6), such analysis does not make use of Game theory, and thus, there is a gap in this respect.

The comparative benefits from competing and cooperating in achieving sustainability have been explored by Carfi & Schiliro (2012), and they have designed a model for this, but did not explore its workings through any real data. Different approaches to corporate social responsibility and corporate sustainability have been explored by Lozano (2011), who suggested a new typology to produce a beginning to understand situation in which companies can influence stakeholders, and where greater influence could be applied. A wider approach has been taken by Wooldridge (2012) to argue that the theory is beneficial in defining problems and identifying significant factors of relevance. Similarly, Yang et al. (2011) were also interested in sustainability and the use of the theory, but their concern was to consider human behaviour and its effect on security.

All of this research shows that Game theory has an application in securing sustainability, and that research is beginning in this area. Such research concentrates more on political aspects, rather than business decision-making, and is basically limited to the arguing of its relevance and the designing of models. To date, no empirical evidence has been produced concerning this. Presumably, this is because it is not really accepted that mineral resources are nearing extinction.

2.18 Utilising Game theory

Games are, of course, competitive and work on the principle that the participants in the game are in competition with each other. The end result is that one is successful at the expense of the others. This is equally true in a business environment, where competition takes the form of such things as marketing campaigns, and if successful, the company gains market share at the expense of other firms in the industry. Indeed, other companies are referred to as the competition. Such a scenario transfers completely into Game theory, and it is normal to consider the competition as a single player, which resolves the game into a two-person game. It is, of course, possible to treat all the competitors as individual players, and to describe the game in this manner. This might be significant in a field with very few players, who are distinct from each other – as in the political arena – but for most purposes, the analysis is not changed significantly (see, for example, Weil, 1966; Szilagyi, 2003), although the mathematics quickly becomes more complex. Therefore, for the analysis in this thesis, the marketplace will be considered in the context of just two players – the company and its competitors.

All major business decisions can be described as strategic decisions, and Game theory is a mechanism for forming these in terms of the decisions and outcomes. In the game, each player – i.e. the company and its managers – choose strategies, that they believe will lead to success, which must be defined as a favourable outcome, and therefore, as winning the game. Indeed, in the political environment, the competition in the nineteenth century between England and Russia in central Asia is commonly known as The Great Game (Frome, 1980); this has now been redefined as a new Great Game with China and India as the imperial powers (Swanstrom, 2005). In deciding upon strategies to be adopted, then companies apply both inductive and deductive logic, as well as attempting to quantify the outcomes.

When cooperation takes place, then it has been argued that the benefits can be increased and shared among the parties involved. How to share the benefits of cooperation has been the subject of much argument, and the methods of calculating the Shapley value to each party (Shapley, 1953) or the Nash cooperative bargaining solution (Nash, 1950) have been proposed in various contexts (see section 6.4). of course, it is necessary to make sure that collusion, and such illegal activity, does not take place: something which is likely to happen, according to Adam Smith (1759), as demonstrated by Suetens (2008). On the other hand, the tragedy of the

commons (Lloyd, 1833), where common value is exploited to the detriment of all (Dube et al., 2016), must also be avoided.

2.19 Summary of the Game theory review

Game theory, clearly, has a useful role to play in the analysis of this topic, and has been used to some extent in the consideration of issues surrounding sustainability, together with political strategies concerning dealing with resource shortage and with extinction studies. However, given that the global extinction of mineral resources has not really been recognised, it is unsurprising that no research has used Game theory to explore this issue. Again, therefore, there is a gap into which, this research will fit.

2.20 Conclusions to chapter

The analysis and critique undertaken in this chapter has shown that, there is a clear gap in the research into which this research will fit. This gap is in the area of the achievement of sustainability and use of mineral resources – when considered at a global level of the planet as a whole – and how to make best use of the resources available for the benefit of the planet. Therefore, the thesis continues with the next chapter being concerned with a methodology for investigation.

Chapter 3

Methodology

3.1 Introduction

The previous chapters have explained the subject matter of the thesis, and have evaluated the state of current knowledge which exists within the literature. In them, it has been shown that there is a gap which would be filled by this thesis, and Game theory is an appropriate method to use for the analysis. The production of a mathematical model using Game theory is the methodology chosen for investigation, and this model will be tested empirically, as well as theoretically. For this purpose, national as well as industrial data is used. In this chapter, these issues are explained, discussed, and justified.

3.2 Flow chart of methodology

As demonstrated through the literature review, there are a number of different factors that impact business decision-making, especially with regards to strategic decisions considering manufacturing; this shows that this process is complex. Sustainability is a significant concern that will develop into more complex problem in future due to diminishing resources. It is more apparent, when energy is considered. therefore, necessarily there must be incentives for countries to become more energy efficient, and this necessity has spread to consumers and manufacturers, both. It seems obvious that this necessity will become stronger, as resources continue to become scarcer in the future. Therefore, it is important to investigate this further, in order to achieve the objectives and answer the research questions.

The methodology adopted enables this investigation. This can be depicted in the form of a flow chart. Therefore, figure 3.1 depicts the flow of the research and method of investigation.

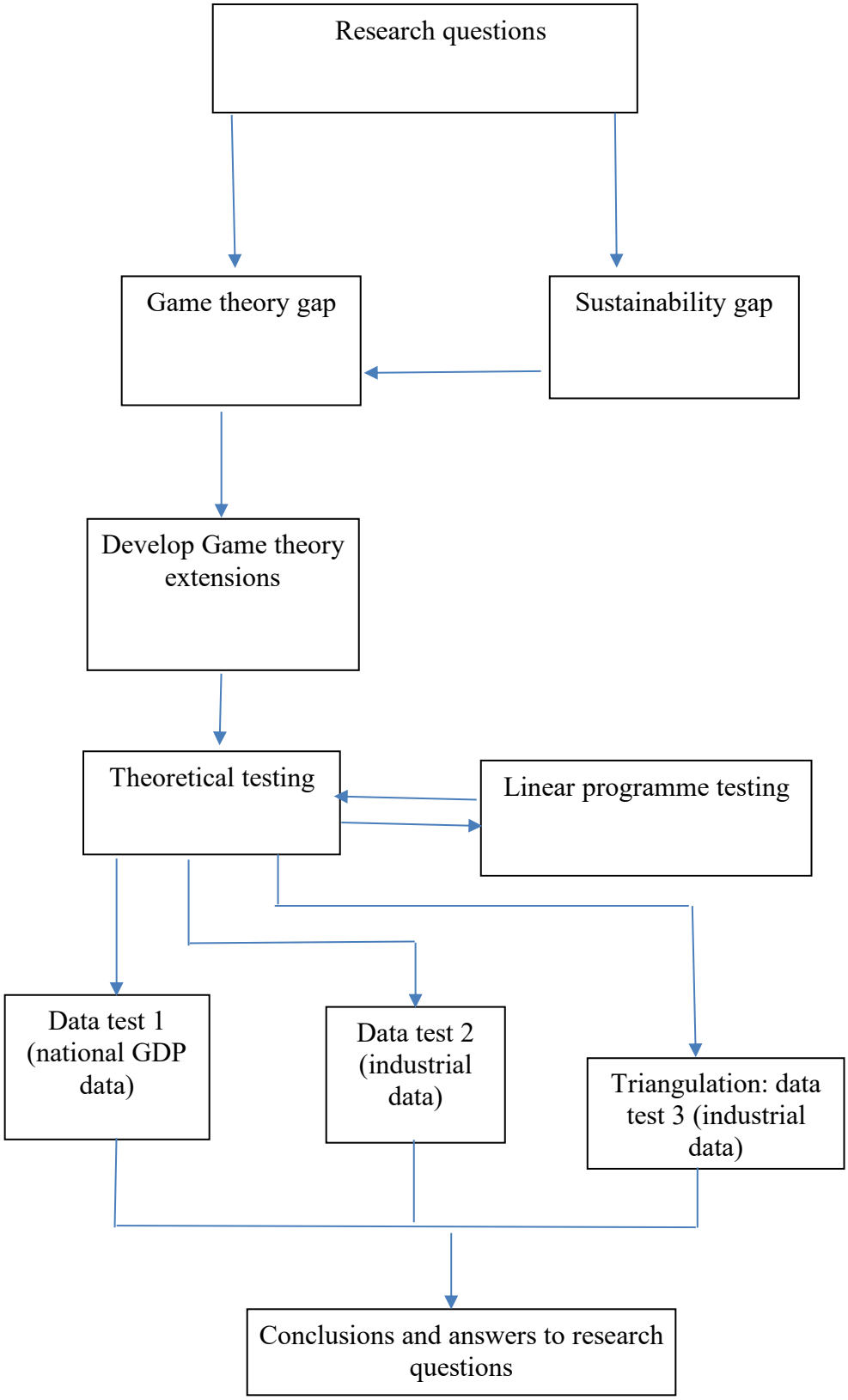

Figure 3.1 – Flow Chart of Research Methodology

This shows that the intention is to develop Game theory to analyse the problems, and to develop it mathematically, before following this up with testing by the use of real data, while also

confirming its validity by applying linear programming to the same situation. This is explained further below.

3.3 Philosophical Consideration

For any research project, it is important to consider the philosophical position which underpins it; in other words, the ontology and epistemology on which it is based, as well as the methodology on which it relies. According to Crowther & Lancaster (2009), these are all based upon assumptions concerning the world. They can significantly affect the way in which the phenomenon under consideration is investigated and the conclusions which will be drawn. Johnson & Duberley (2000: 1) support this by stating:

> "...how we come to ask particular questions, how we assess the relevance and value of different research methodologies so that we can investigate those questions, how we evaluate the outputs of research, all express and vary according to our underlying epistemological commitments. Such epistemological commitments are a key feature of our pre-understandings, which influence how we make things intelligible".

Crotty (1998: 17) also supports this when she states that:

> "…in our observing, our interpreting, our reporting, and everything else we do as researchers…we inject a host of assumptions. These are assumptions about human knowledge and assumptions about realities encountered in our human world. Such assumptions shape for us the meaning of research questions, the purposiveness of research methodologies, and the interpretability of research findings".

Ontology forms the base of any philosophical position, as it determines one's beliefs concerning the nature of reality, and how the various parts interact with each other (Gruber, 1993). As far as social reality and our knowledge is concerned, then it can be divided into an objective reality and constructive reality (see Grix, 2001). Alternatively, it can be divided into constructionism and realism (Delanty, 1997). These are concerned with one's view of the world and the extent to which, it is possible to separate the research from the object of study. They also determine the means, whereby the research gives meaning to the social phenomena observed. Essentially, one is a positivist view of the world, which holds that reality is fixed,

and only needs to be discovered, and measured (Crowther & Lancaster, 2009). The other is the social constructivist view of the world, which holds that reality is interpreted by us as individuals, who give meaning to the object of research, by the way in which we interpret the phenomena observed (Andrews, 2012). Here, the focus is upon interpretation rather than measurement. Crowther & Lancaster (2009) describe this differently, by stating that ontology can be divided into the opposing views of realism and interpretivism.

Epistemology follows from ontology, in that it extends the views into a consideration of how reality can be known, and therefore, researched (Hughes, 2011). This, effectively, determines which theories and models are preferred by the researcher (Gettier, 1963). The various stances in belief have been described as paradigms by Kuhn (1962). Easterby-Smith, Thorpe & Jackson (2008) explain that the epistemology of the researcher determines the methods involved in researching the problem. Indeed, Hughes (1990: 6) states:

> "In making a knowledge claim, whatever it may be, one is also indicating a preparedness to justify that claim by pointing to the ways in which one knows".

3.3.1 Competing paradigms in business research

Conventionally, research in business studies is dominated by two different research paradigms, leading to two different research cultures. These have been described by (Johnson & Onwuegbuzie, 2004) as positivism and interpretivism, and by Easterby-Smith et al. (2008) as positivism and social constructionism. These two research paradigms (i.e. positivism and its alternative of either interpretivism or social constructionism), and a third (which allows a multi-method approach and their usefulness for research purpose) are discussed in the sections below. Although this thesis is related to resource consumption in the production process, it has already been established in chapter 2 that this is inevitably related to people through consumption and management, both. Therefore, for this research, the same interpretations (i.e. positivism and interpretivism or constructionism) are relevant.

As an alternative to the religious terms and taxonomies previously used to conduct enquiries into social phenomena, positivism was invented to provide a more objective method of explaining a phenomenon and generalising the results obtained (Kim, 2003). This was achieved by providing for independence of the observer from the subject being observed. As expressed

by Easterby-Smith et al. (2008: 57), “the key idea of positivism is that the social world exists externally, and its properties should be measured through objective methods rather than being inferred subjectively through sensation, reflection or intuition”. Positivism is argued to enhance analysis by reducing the whole to its simplest possible elements, by looking for causal explanations and fundamental laws (Easterby-Smith, 1991; Remenyi et al., 1998; McLeod, 2008). This mode of investigation has been described by the use of such terms as quantitative analysis, empirical analysis, mathematical analysis, hypothesis testing, etc. (Lee, 1991). Positivism is particularly deductive in approach, in that it is aimed at testing and assessing the validity of known theories or hypotheses through their application to real world data (Crowther & Lancaster, 2009). To the extent that positivism entails the collection of views from many people about a phenomenon, it is economical, saves time, and can be relevant to policy decisions (Easterby-Smith et al., 2008).

Despite this robust way of looking at, and describing knowledge, some identified limitations have put its suitability for all research purposes in question. It has been pointed out that dogmatic adherence to positivism can paradoxically jeopardise the soundness of research in the social science through ignoring certain influential contextual factors in organisations (Kim, 2003), particularly as it relies upon large data sets of relatively superficial data. Easterby-Smith et al. (2008) also opine that the rigid nature of positivism renders it ineffective in understanding actions, and does not serve useful purpose in generating theories. Conversely, it does have merit in assessing the validity of extant theories and their falsification (Popper, 1959). Questioning the suitability and relevance of positivism as a philosophical underpinning, Denscombe (2007) argue that positivism and scientific model of enquiry, only provide an aspiration, and bear little resemblance to actual practice in real social settings.

The claim that the social world cannot be understood by excluding subjective analysis of actions (Johnson and Duberley, 2000) led to the prominence of the interpretivistic approach to research. This assertion also finds support in those of Bryman (2015), inter alia, that social constructionism as a new paradigm over the last half century was developed as a reaction to the claim of social reality being understood through the positivist / scientific approach. It was also developed as a counter argument that reality is not objective and exterior, but is actually socially constructed and given meaning by people (Burr, 1995). Crotty (1998) argues that constructionism and interpretivism are a part of the weapons used in attacking the dominance of objectivism and positivism, while she also suggests that interpretivism has emerged in

opposition to positivism in attempting to understand and explain human and social reality. It can safely be said that despite its claimed shortcomings, positivism still remains the dominant paradigm in management research (Johnson and Duberley, 2000).

It is important to consider that in the philosophy of science, Feyerabend (1975) argued against scientific method and epistemological conformity in claiming that science is an anarchic enterprise. In other words, he claimed that progress came from stepping outside the established tradition. This was echoed by Derrida (1978), who claimed that critique came from within and led outside. This is a step forward in the developing of theory from the seminal works of Kuhn (1962) and Popper (1959), who were concerned with explaining paradigm shifts, and more in tune with Tinker & Puxty's (1995) description of how debate becomes closed down once a new paradigm is accepted. Sadly, all of these writers were prescient in describing the way that the discourse becomes closed and enters the mainstream – for, this is exactly what has happened within the sustainability discourse. It is part of the eternal quest for legitimacy (Crowther & Carter, 2002), with academics seeking to position their work within the mainstream discourse, in the belief that this will add to knowledge, and not simply enhance their own careers. This thesis attempts to step outside and to show some developments that can thereby occur.

Constructivism considers that knowledge and reality are dependent upon human practices, constructed in and out of interaction between human beings and their world, developed and transmitted within an essentially social context (Crotty, 1998). As a competing paradigm to positivism, it seeks understanding of values, beliefs, and meanings of phenomena (Wardlow, 1989) through continuous interaction. According to Easterby-Smith (1991), it adopts qualitative and naturalistic methods to inductively and holistically understand human experience in context-specific settings. Rather than seeking causality and generalisations, interpretivism attempts to develop theories through explanatory methods (Amaratunga et al., 2002).

This epistemology is also known as phenomenology, and it is also argued to be replete with shortcomings. Babbie (1993) considers that researchers' views are reflected in the interpretive process, and that therefore, their personal subjectivity may introduce bias into the research findings and conclusions. Other documented limitations of interpretivism include: expensive and tedious data collection methods, difficulty in analysing and interpreting collected data,

harder control in terms of the pace, progress, and end points of research process, and low credibility given to the results by policy makers (Easterby-Smith, 1991).

The ensuing debate between the proponents of these two paradigms and the need to find a common ground led to the emergence of other paradigms, such as critical science, critical realism, postmodernism, pragmatism, pluralism, etc. (Mingers, 2004). Those advocating a blend of the two paradigms point out the commonalities between the two (Sechrest & Sidani, 1995; Sandelowski, 1986), particularly in terms of objectives, scope, and nature of enquiry (Dzurec & Abraham, 1993), and argue that researchers and research methodologists should only be concerned about the usefulness and appropriateness of each approach for their research enquiries, and when they should be combined (Johnson & Onwugbuzie, 2004). Indeed, Easterby-Smith et al. (2008) noted that whilst a trend of departure from positivism towards constructivism can be seen from the 1980's, management researchers have taken a pragmatic view by embarking on a deliberate combination of methods, which draw from the two paradigms.

Given the increasingly interdisciplinary, complex, and dynamic nature of modern research, the need to complement one method with another becomes necessary, as researchers need to have a good understanding of all other paradigms to enhance communication, promote collaboration, and accomplish superior research (Johnson & Onwugbuzie, 2004). Sharing the belief that multiple approaches can be used to tackle research problems (Rossman & Wilson, 1985), this study is based on positivism, although the interpretation is also based in pragmatism.

3.3.2 Positivism

Positivism is based on the assumption that all knowledge is based in actual facts, rather than their interpretation. Thus, information is derived from our sensory experience, and interpreted through logic and reason, and this forms the only source of all certain knowledge (Larrain, 1979). Positivism holds that all valid knowledge which represents truth is only found through this method.

The pursuit of scientific truth can be traced back to the philosophy of Plato and Aristotle in Ancient Greece. Plato believed that such a pursuit should be based on pure contemplation and

the search for first principles; that is, an approach based on deduction. Although Aristotle had been responsible for this focus on first principles, he had also earlier established the basis of the inductive approach through stressing the importance of classifying empirically observable phenomena. While Positivism embraces the quest for truth and the notion of objective knowledge inspired by Plato, it also rejects the metaphysical and idealist character of Platonic philosophy.

The emergence of rationalism and empiricalism from the time of the Renaissance, gradually replaced clerical authority and the prevailing assertion of the Middle Ages, that knowledge derives from 'the ancient authority of the Church'. The experimental method emerged alongside the development of modern science, from Renaissance thinkers and scientists such as Leonardo de Vinci, to those of the sixteenth and seventeenth centuries such as Galileo Galilei, Francis Bacon, and Isaac Newton. Delanty (1997: 17) argues that "it is important to see that modern science emerges at a time when the institutions of the Middles Ages, such as the Church…were collapsing, but when the social and political order of modern society had not yet consolidated."

The emergence of Positivism – alongside and within the social sciences during the nineteenth century – owes much to Comte, the French philosopher, who outlined the basic ideas of Positivism in his *Course of Positive Philosophy* (1865). Comte was an empiricist for whom there could be no truth without observation. For Delanty (1997: 26), "social science…thus began its uncertain career in the mirror image of natural science and came to be the expression of modernity itself." Comte greatly influenced the work of Mill and Spencer in Britain during the mid-nineteenth century, and Durkheim (1895) in Germany at the turn of the century. Empirical social science was readily embraced by US universities from the start of the twentieth century, culminating in the rise of the Chicago School, which represented the leading school in sociology during the 1920s. At around this time, the 'Vienna Circle' were instrumental in bringing about an extreme version of Positivism, termed 'Logical Positivism' (Smith, 1986), in reaction to what they saw as the rise of obscure metaphysics and the anarchy of ideology within academia. Logical Positivism was based on the notion of a unified science centred on mathematical logic; it embraced only two kinds of knowledge: (1) empirical knowledge (derived from observation), and (2) logical knowledge (derived from logical analysis).

The hegemony of Positivism during the inter-war years was achieved within the sciences through 'Logical Positivism', and in the social sciences by the rise of what Delanty (1997) terms a 'professional empirical social science'. However, in the post-war period, Positivism was attacked from two fronts; firstly, from social scientists, who reacted against the dominance of the scientific method and of the natural sciences over the social sciences; and secondly, from within science itself.

As this thesis starts with extensive mathematical (Game theory) development and analysis, it must inevitably be based in the positivist ontology. However, the analysis is based upon this followed by analysis of real data, and then, interpretation; therefore, the ontological basis adopted must be based on more than one discourse.

3.3.3 Mixed Method approach to research

As suggested by the discourse on philosophical underpinning, this study uses more than one approach in its method of inquiry or research design; hence, there is the need to shed more light on this approach. While this method of inquiry has come under different names and terminology, it is here referred to as the mixed method approach.

There is a convergence of opinion among scholars that the combination of quantitative and qualitative data (both in collection and analysis) in a single study indicates mixed methods research (Brewer & Hunter, 1989; Howe, 1988; Miles & Huberman, 1994; Patton, 1990; Rocco et al., 2003; Hurmerinta-Peltomaki & Nummela, 2006). The underlying assumption of combining methods is that the combination would yield a better result, with the strength of one method neutralising the weakness of the other (Denzin, 1989). For example, quantitative and survey data addresses the question of breadth, but ignores that of depth, while qualitative or interview data addresses concerns relating to depth, but fails in regard to breadth. As noted by Crowther & Lancaster (2009), achieving effectiveness in management research may require combining inductive (qualitative) and deductive (quantitative) methods. Creswell & Plano Clark (2007) also argue that combining qualitative and quantitative data gives a holistic picture, which takes note of trends, generalisations, and in-depth knowledge of participants' perspectives, particularly when the potential exists for one form of enquiry to contradict the other. This was succinctly pointed out by Scandura & Williams (2000), when they stated that combining qualitative and quantitative data would – among other considerations – enhance

generalisability of the results. The combination of methods would also be considered appropriate when the results obtained through one method – for example quantitative – are not sufficient to explain the outcomes, such that a qualitative data set – particularly in the participants' own words – is necessary to give better interpretations of the results (Creswell & Clark, 2007). Besides, Scandura & Williams (2000) noted that using mixed methods would enhance covering all the four aspects of validity – internal, external, criterion, and construct validity. However, this thesis does not make use of qualitative data except insofar as the interpretation in Chapter 6 using qualitative factors as well as quantitative, and so the method is referred to as multiple, often referred to as the mixed methods approach.

The objective of explanatory design is to provide explanation for quantitative results with qualitative data, in cases of significant/insignificant outliers, or unexpected results (Morse, 1991), or as expressed by King (2004), to validate particular measures, or to clarify and illustrate the meaning of the quantitative findings. The exploratory design seeks an in-depth exploration of a phenomenon by using the results of an initial qualitative data set to develop an instrument, which allows for a quantitative analysis and results, thereby enhancing its validity and generalisability.

Though the merits of using combination of methods have been discussed above, its relevance can be found in the complexity and dynamism that characterise issues in the field of this research. Using multiple methods in organisational research has been argued to lead to varied and rich perspectives on the phenomena under investigation (Easterby-Smith et al., 2008). In line with this thought, Filstead (1970) states that studying human behaviour in social settings requires not only the use of scientific method (empiricism or quantitative approach), but also the interpretative or phenomenological methods (inter-subjective and trans-objective) to understand the data.

The approach adopted in this study finds expression in the statements of Kim (2003), that although the quantitative method is best suited for research in this field because of its ability to uphold best the validity of findings and generalisability of results, researchers should also be mindful of the benefits that flow from the mix and application of other methods, as a vehicle for increasing the depth of research. Indeed, Scandura & Williams (2000: 1250) contend that in addition to multiple methods "resulting in a more robust and generalisable set of findings,

recommendations [from the findings] for managers could be made with greater clarity and confidence".

Scherer & Palazzo (2007) argue that a positivistic orientation only leads to instrumental interpretation of corporate responsibility, which strengthens the economic theory of the firm, but fails to capture the normative perspective. Most studies, that have utilised the quantitative approach as initially applied here, have only used this quantitative approach, without recourse to verifying the results with qualitative data; therefore, the current work will be the first attempt at examining the construct of interest using qualitative and quantitative approaches. Put differently, while prior studies have only been positivistic in approach, this study will add the interpretivism flavour to this mode of enquiry, culminating in a pragmatic approach, which gives emphasis on what best describes or provides best explanation of the phenomena being investigated. From the point of view of Creswell & Clark (2007), ontologically-wise, this study adopts singular and multiple realities; epistemologically-wise, it adopts practicality in terms of giving emphasis to data collection that best addresses the research questions; axiologically-wise, it adopts a multiple stance – biased and unbiased perspectives; and methodologically-wise, it adopts combining of qualitative and quantitative data.

Multiple methodologies seem to be the norm for research in the management disciplines, but the favoured ontological position is that of positivism. As this is a mathematically based thesis, then it seems that only positivism is suitable, and consequently a positivist ontology and epistemology is adopted in this thesis, supplemented by others for the discussion in Chapter 6.

3.4 Methodology adopted

The methodology adopted in this thesis underpins its ontological and epistemological positioning, and makes use of various methods. In order to analyse the problem, a variety of techniques are used – firstly to undertake a theoretical analysis, and then to undertake an empirical analysis using real data.

3.5 Economic equilibrium

Economics is concerned with ensuring economic activity takes place in an efficient manner. As such, it assumes that products exist for which there is a demand, and that supply and demand

can be matched in manner which is effective to all concerned. The basis of economic activity is the price system which assumes that supply and demand will come into equilibrium via changes to price. Thus, if demand rises, then price will rise, which will call more resources into the market, which will reduce price to an equilibrium position. Alternatively, the rise in price will reduce demand until equilibrium is attained.

The basic model assumes that supply can readily be increased, while demand is equally readily reduced, and that these changes will be mediated though the pricing mechanism. However, there have been a number of studies looking at exceptions, and one strand is concerned with scarcity. Thus, for example, Malthus (1798) has been credited with originating this line of study by considering the way in which population increase will lead to scarcity in food supply. Although out of fashion for most of the twentieth century (Boserup, 1983), when plenty was the norm, this theory has more recently been reintroduced to look at many aspects of natural resources. Thus, for example, Audi (2013) considers fresh water shortage in Nigeria, and Lambin (2012) considers land scarcity, while Cairns (1990) claims that such theory does not apply to minerals, and Scott & Pearse (1992) claim that technology can compensate for any shortage in supply.

If this is applied to the mineral resources of the world, then the situation is more complicated. In general, supply becomes more restricted as sources reach maturity, and then become nearer to exhaustion. Moreover, unit costs of extraction tend to increase as supplies become more difficult to extract. This can, of course, be obviated by technological development (Dehghani & Ataee-pour, 2012). Nevertheless, it can be expected that price will increase in order to lead to increased supply, either through further exploitation of existing mines, or the calling of new mines into economic operation. Furthermore, there is a continual need for prospecting, in order to find new sources to extract, but again, as mineral resources become depleted, then even the cost of prospecting increases. Therefore, the conclusion must be that as mineral resources become depleted, then unit cost of supply will increase regardless of any developments.

If demand increases, the rise in price will encourage more mining to take place, but often the extraction of additional minerals is at an increasing cost (Young, 1991). Additionally, there may be political implications. The resources are in finite supply, and this is not infinitely expandable but restricted to available resources, particularly to resources which are extractable with current technology. Changes to technology can increase the available supply, such as the repurposing

of oil rigs in the sea to extract cobalt therefrom. Additionally, for resources such as oil, availability is governed by the possible rate of extraction, rather than the amount actually available. Thus, there are a number of reasons why the pricing mechanism does not operate as effectively as is generally imagined for these resources.

In general, when price rises, then demand reduces, with the exception of the Giffen paradox[34] and the Veblen paradox[35]. As far as minerals are concerned, there are other implications. Thus, if price rises, then this stimulates technological development which leads to a reduction in the need for the mineral concerned (Ayres & Peiro, 2013). It also leads to the consideration of alternatives for the mineral concerned, and to a focus upon recycling of such minerals (Binnemans et al., 2013). Of course, such minerals display the Jevons paradox as demand continues to increase due to the continual development of the world.

One further complication in terms of sustainability is that when resources are restricted in availability, then the price mechanism is not necessarily the best means of allocating resources. One problem with this mechanism is that those who are best able to pay will acquire the resources. In other words, all available resources will flow to the richest countries, which are the developed countries of the western world. This inequality will not lead to sustainability, which requires satisficing for all. Indeed, it only takes into account economic utility and not social utility of the use to the resources.

As it becomes more apparent that resources are depleted and in increasingly short supply (Krautraemer, 2005), then the normal assumptions of supply and demand maintaining equilibrium through the price mechanism will cease to apply. Minerals are necessary for some activities, and can be considered to be luxurious for others. But the price mechanism assumes that need is related to demand, and can be accommodated in the price of minerals. However, on this assumption, utility is ignored, and ability to pay is equated to, both, demand and utility. Thus, someone who can afford to pay for expensive ornamental items for decoration is assumed to have greater need than someone who requires the same minerals for basic living needs: economics assumes that the rich person derives greater utility from the use of the scarce mineral

[34] For a Giffen good then as price rises demand also rises as the good is seen to become more desirable (Marshall, 1890).
[35] Veblen (1899) created the notion of conspicuous consumption when it is desirable for someone to be seen to consume something expensive as it increases the perceived status of that person.

than does the poor person. While being a disavowal of natural justice, this is also anathema to any concept of sustainability. Sustainability requires social sustainability, as well as environmental and economic, and this cannot be achieved when some have a surplus for ornamental reasons while others have a deficiency of basic requirements.

3.6 Research questions

While it is accepted that technological developments will take place and substitutions will occur as well as recycling of previously used material, there is a finite amount of each mineral available. Given the depletion of mineral resources, it becomes pertinent to decide how the available resources are utilised. Therefore, the purpose of this thesis is to answer the questions:

1. Does resource depletion have an impact upon the way firms acquire the resources for their production, and if so, then how?

    - And its corollary that given the finite amount of mineral resources available, what is the best use which can be made of them?

Naturally, in order to decide upon best use, then a criterion for evaluation must be determined. The ultimate criterion must be the achievement of sustainability, and what is meant by this term is the sustainability of the planet and human life thereon (Brown et al., 1987). This requires a balancing of the three pillars of the Brundtland definition of sustainable development, namely economic, environmental and social aspects. Of course, such a balancing does not need to be equal – merely balanced. Moreover, it does not necessitate equal division between the various people and countries of the planet, but it must be accepted to be equitable. The consequence of any perceived inequity would be conflict, as people sought greater equity. Ultimately, the decision as to how to balance the three pillars and divide resources between countries and people is partly a political decision and partly a moral question. As such, there is no clear answer as to what is best. So, what is sought in the thesis is to consider what ways the mineral resources available can be distributed throughout the planet in the most effective way.

Therefore, the problem for this thesis is one concerning the allocation of resources (and by resources is meant the mineral resources of the planet), and can be expressed in terms of the following question:

2. What changes are needed to address the issue of depletion for sustainability in the global market?

- And its corollary of what is the best way to allocate the mineral resources of the planet to optimise their use?

This can be considered as a concern with the effectiveness of the pricing mechanism, as a means of doing so, versus the effectiveness of an allocation system based upon perceived needs / benefits. This would require an alternative system for deciding upon needs and allocating accordingly. The closest alternative which has existed, seems to be the soviet command economy, where decisions were made centrally and compliance enforced. For the planet, however, this would require the agreement of all the countries of the planet, and would require some form of governance and regulation in order to work effectively, just as the pricing mechanism currently requires governance.

For simplicity, the method based upon pricing has been labelled the competition method, while the method based upon allocation has been labelled the collaboration method. The prime research questions to be answered in this thesis, therefore are

3. Would a new approach to the global management of distribution of planetary resources be beneficial?

4. What kind of interventions, if any, are needed for effective management of the resources of the planet?

And their subsidiary questions:

- Is either competition or collaboration more effective in the allocation of mineral resources?
- If so, which method is more effective?

With further subsidiary questions:

- Would this benefit the sustainability of the planet?

- What difficulties may ensue in achieving this optimum allocation?

3.7 Method of investigation

The methodology adopted in this thesis underpins its ontological and epistemological positioning, and makes use of various methods. In order to analyse the problem, a variety of techniques are used – firstly to undertake a theoretical analysis, and then to undertake an empirical analysis using real data.

3.8 Bayes Theorem

This study is chiefly related with the impact of availability of raw material and their depletion and what the meaning of this is to the manufacturer. The techniques of industrial engineering[36] can be useful in understanding this and to show that this understanding of the resource implications will lead to the making of different decisions; thus, it is important to explore how. To commence this, an explanation of Bayes Theorem is needed to show how its use leads to the creation of Game theory as a method of analysis in business decision-making. It commenced when Reverend Thomas Bayes (1702-1761) formed his interest in the use of probability theory in mathematical terms, and started to consider that probabilities were changed when additional information was obtained. This led to the creation of what is now known as the Bayes theorem of conditional probability. Simply this states that:

> The probability may change when additional information on subsequent events is obtained. Therefore, the probability has a consequential value in decision-making.

Algebraically, we can express Bayes theorem as:

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

Bayes Theorem is a valuable tool for business decision-making (Crowther, 1996), because it enables quantification of the value of acquiring extra information, and shows how this new information can change the effects of any decision. Also, its use helps to focus upon the

[36] Such techniques are also used by management accounting and production management.

important factors in the decision because of this quantification and the quantification of the risks which may be attached to the alternative decisions which are possible. Therefore, it makes any comparative analysis of the available alternatives more rigorous. Importantly, it also shows the value of any additional data and whether it is worth the effort of acquiring it. So, it has become an important tool for management decision-making.

In practice, there are a variety of issues involved in the use of this technique to analyse business strategy problems. As Park, Amarchinta & Grandhi (2010) have shown, these are concerned with the quantification of the effects of the various alternatives and the assigning of realistic probabilities to each. The technique is only as good as the quantifications arrived at and the probabilities assigned to them. Quite obviously, there is effort (and cost) associated with arriving at values for this, but if they are to be of value in making these strategic decisions, then these quantifications need to be as accurate as possible – the more accurate, then the more accurate the determination of the outcomes and the decisions made therefrom. The question of effort and cost in improving the information for these quantifications needs to be considered, and a pareto optimum must be arrived where extra effort is not worth the increased accuracy. Nevertheless, the technique does introduce a more rigorous approach to the identification of the available alternatives and the effects of the decision, and it is beneficial just for this reason; hence, decision-making is facilitated and improved thereby.

A further problem, which is common to most management decisions, is that they assume that the decision can be made in isolation and without taking into account such things as retaliation by competitors or any other decisions which the managers in the company may take. Bayes Theorem suffers from this problem also, and the result is that in actual practice, decisions are never taken in isolation and in most cases, it is impossible to fully quantify all factors involved in any such strategic decision.

Nevertheless, this theorem shows that the complexity of decision-making can be improved by treating the decision and its components in an iterative manner. It also highlights that additional information is valuable, as long as the costs of acquiring it is less than the value of the increased accuracy ensuing. These are factors which are addressed by Game theory, the method to be adopted which does not rely upon such accurate quantifications for decision making.

3.9 Application of Game theory

Techniques based upon Bayes theory, discussed above, are helpful for decision-making, and particularly to make operations decisions, but for complex strategic decisions, Game theory is the most helpful technique (Shapiro, 1989; Amadae, 2016). This is especially the case when considering marketing and pricing decisions, as these are more likely to encounter different effects, including responses from the external environment (e.g. from competitors), and it is here where interaction with customers takes place. These decisions are often more complex than production and engineering decisions, but increasingly, with resource depletion becoming more apparent, the acquisition of raw materials becomes more competitive, with a consequent increase in transaction costs, and these decisions also interact with the external environment. Thus, it is necessary to consider such things as competition, as these will be affected by the decision and are likely to respond to the actions of the firm, and even to act in anticipation. Equally, these competing firms are making their own decisions about such matters as marketing strategy, pricing position and production. In such a situation, the firm and its decision makers can be regarded as in competition with another firm and its decision-makers, and the generic term to describe this kind of situation is that of a game. And Game theory can help to model this kind of situation (Carmerer, 1991) – even though it has not been greatly used – and therefore, improve the decisions made. One important aspect of Game theory is that absolute values are not needed to understand strategic decision-making, but only relative values – that is, the relative values to the decider of the alternative courses of action. This differentiates the theory from mathematical decision-making tools, which rely upon quantification to evaluate the effects of different decisions.

Often, there is a need for managers to formulate complex problems in order to make business decisions, and Game theory is of much assistance in this, enabling decision alternatives (and consequences) to be clearly seen and compared. It enables the decisions to be described as steps in the game and quantified accordingly, and this is especially useful in dealing with a complex problem. Quantification is, of course, based upon probability theory, and therefore the problem of assigning accurate probabilities exists, just as it does in all other business decision-making tools and techniques. Therefore, it can be unreliable for this reason, but is especially useful in describing and incorporating other factors in the decision, which may not be subject to quantification but are nevertheless important. Thus, management behaviours, such as bluffing and forming coalitions can be incorporated into the problem analysis and its possible

solutions. This is all a part of the repertoire of management behaviours which is difficult to model in practice, but by using Game theory, it is possible to formulate the problem in terms of the decisions needed (and their consequences); therefore, this enables the theory to be widely used in actual practice.

It has already been argued that strategic decisions are never taken in isolation, and it is problematic to quantify them as if this was the case. This becomes especially true when the decision is one upon the external environment, such as a marketing campaign, a product launch, or concerning the acquisition of raw materials. Here, it is necessary to consider the effects upon customers or competitors or suppliers, and the likely reaction. For competitors and suppliers, then anticipatory action must be considered, as well as possible reaction. In this situation, the firm and its decision-makers can be regarded as in competition with other firms, and this situation can best be described as a game. It is in such a situation that Game theory becomes a valuable technique.

In a competitive situation like this, then it is normal that there is only one winner and the other competitors are less successful, if not actually losers. In the situation such as this, the game can be viewed as consisting of only two players (the company itself and all competitors). This makes the analysis simpler, without making any significant change to the analysis needed. It is, of course, possible to model the situation as a game with three, four, or many more competitors. This makes the mathematical analysis much more complicated, without making the effects of the analysis any more robust (see Garey & Johnson, 1979). The only situation where this is not true is a situation of oligopoly, where the other players are expected to behave differently from each other. The number of situations in which this scenario arises is very few, when there are three or four players, who are very different from each other. For the analysis undertaken in this thesis, it is considered that it is sufficient to consider only a two-person game – consisting of the company itself and the competition (considered generically).

Game theory provides a method of formulating a business situation in terms of strategies – the strategy of the decision-maker and the strategy of his / her opponent – and in term of outcomes. Each player in the game selects and executes those strategies which (s)he believes will result in ‘winning the game’, that is, will result in the most favourable outcome to the problem situation. In determining this strategy for winning, each player makes use of deductive and inductive logics and attempts quantification of the outcomes.

Therefore, Game theory is to be of assistance in managerial decision-making through its ability to formulate the decision in terms of a problem, which can be solved quantitatively to arrive at a decision. All the techniques – which have been used for such decision-making – have been based upon probability theory – with the problems associated with attaching the relevant probabilities before making quantifications. Game theory is no different. However, Game theory is particularly useful in situation of strategic decision-making, where relative probabilities are more important than the attachment of actual values to the probabilities. In such a situation, the political expertise of the managers (for example bluffing, negotiating, bargaining and the forming of coalitions) become more important, and this theory can help model outcomes from these. This is why Game theory is used extensively in the political arena and among countries. Game theory is very useful for problem-formulation and the consideration of options and relative risk rather than actual quantifications. But many strategic decisions are of this nature. Normally, the managers are able to use their judgement and experience to make decisions, once the problem has been accurately formulated.

One aspect of Game theory, which is of significance and which is very representative of real-world situations, comes from the use of probably the most powerful game studied – the Prisoners' Dilemma. This game is interesting because there exists a Nash equilibrium for each player, which is not the pareto optimum; this is never reached by the players without some outside interference and motivation. As this thesis is studying the interactions of firms within the market place, then it is necessary to study that market place and interferences which can take place. In other words, the inefficient operation of the free market system is pertinent, and so too is control through governance and regulation. Thus, the analysis being undertaken needs to be extended from simply studying the decision-making process to looking at how it works within the market place. Thus, the units of analysis need to be individual firms (and their decision makers) as well as the global markets themselves (and their governance and regulation). This will involve the economies of countries as well as international regulation.

3.10 The Prisoners' Dilemma

One game which is frequently used to explain the concept of dominance is known as the Prisoner's Dilemma; a scenario first devised by Flood (1952). It was subsequently named as the Prisoner's Dilemma by Albert Tucker (see Poundstone, 1992), who developed the prisoner scenario. The Prisoner's Dilemma is a game concerned with strategic analysis and decision-

making between two parties. Each party has two possible strategies to adopt, and these are either to cooperate or to defect. In figure 3.1 below, these are labelled: for player I as C and D, and for player II as c and d.

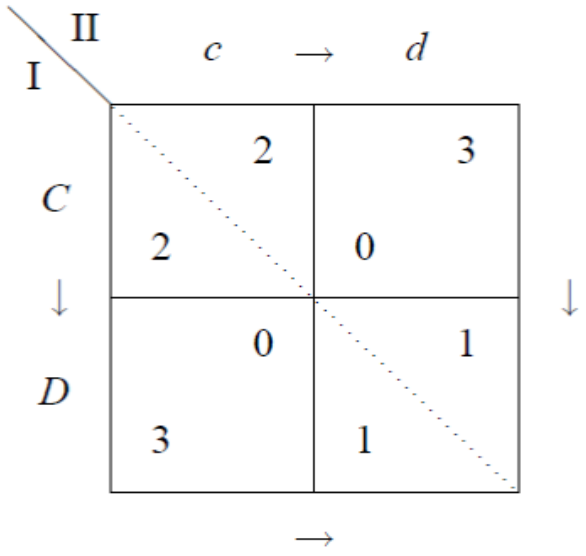

Fig 3.2 – Prisoner's Dilemma

The figure illustrates the payoffs which arise in the game according to which options are chosen by the two parties. Player I will choose either row C for cooperate, or row D if deciding to defect. At the same time, player II will choose either column c or column d, according to whether a cooperate or defect decision is made. The result for player I is shown at the lower left of each square while the upper right is the result for player II. It can be seen that the dominant strategy for each player is to defect even though this does not lead to the best outcome, which will not arise solely through the players acting rationally. Interestingly therefore, neither will cooperate, unless some outside influence requires this decision.

The name of Prisoner's Dilemma is from a puzzle created with a situation of two prisoners, held as suspects of a crime. There is no strong evidence of who has committed the crime, unless if one of them testifies against the other. In case one of them testifies against the other, then he will be rewarded by being released (payoff 3), but the other one will be sentenced to prison for a long time (payoff 0). However, in case both of them testifies against each other, they will both be punished by a short prison sentence (for each one, payoff 1). In case they both cooperate by not testifying, then they will just be punished for a minor offense (for each one payoff 2).

This is the mutually beneficial outcome for the game, but the analysis shows that defection (to testify) gives a higher outcome for each individually, regardless of what the other decides to do. This, therefore, is the dilemma of the game.

The game of Prisoner's Dilemma applies in a wide number of contexts in the political and strategic environments, where individual defections at the expense of others results in an overall outcome which is less desirable. For instance, situations like the arms race and proxy wars, or environmental pollution can be mentioned. It is equally common in the business environment and examples include cut-price marketing and choosing to litigate rather than agree a settlement[37] – all cases where the result would be detrimental to the parties. Its Game theory justification, sometimes leads to the introduction of laws and treaties which coerce cooperation.

The interesting point behind the scenario in this game is that there is a pareto optimal decision, but this is never chosen, because rational decision-making leads to alternative decisions being made - even though the pareto optimal decision is always the best one. Interestingly, the Nash equilibrium in this game is not pareto optimal, which explains why the best outcome is never arrived at - an unfortunate situation. This in part explains the problem with arriving at an agreement internationally about climate change.

Game theorists have attempted many approaches to overcome the obvious non-optimum outcome of the Prisoner's Dilemma Game. As an instance, this game is basically changed if played with a sequence of rounds. When this game is repeated, then patterns of cooperative behaviour might be established as economic rational behaviour, because parties' worry of future punishment outweighs the benefit that they can get by defecting each other today. Indeed, Dietz & Zhou (2011) argue that there are situations in which, cooperation can emerge, although they fail to explain such situations.

Nevertheless, although the Nash equilibrium will be chosen rather than the pareto optimal decision, which will never be chosen in a single round game, it is possible to arrive at a cooperative approach in a game repeated over several rounds. Strictly speaking, it is not really a cooperative answer; rather, it is a stable situation where each player retaliates by copying the

[37] A prime example of this would be the McLibel trial of 1997 (http://www.mcspotlight.org/case/)

decision taken by his / her opponent in the previous round. This was demonstrated by Rapaport (1966), and described by Axelrod (1984) as a tit for tat strategy.

By analysing the outcomes of successful strategies, Axelrod (1984) stated several conditions necessary for a strategy to be successful:

Nice

The most important condition is that the strategy must be "nice": in other words, a player will not defect before the opponent does - also known as an optimistic algorithm. Almost all of the most successful strategies are nice: a purely selfish strategy will not cheat on its opponent, for purely self-interested reasons first.

Retaliating

The successful strategy must not be a blind optimist, and always play cooperatively. There must sometimes be retaliation. An example of a non-retaliating strategy is Always Cooperate. This is a very bad choice, as nasty strategies will ruthlessly exploit such players.

Forgiving

Successful strategies must also be forgiving. Though players will retaliate, they will once again fall back to cooperating, if the opponent does not continue to defect. This stops long runs of revenge and counter-revenge, maximizing outcomes.

Non-envious

The last quality is being non-envious, that is not striving to score more than the opponent as the objective in itself.

It should be noted that this is a successful approach for playing in a competition, but is less successful and less realistic when applied to business decisions. Here, it tends to be always true that intervention is needed before the pareto optimal strategy is adopted by all; in effect, regulation within the market is always necessary. This is something which will be returned to several times in subsequent chapters.

Mathematically, the scenario involving the Prisoners' Dilemma in a business decision-making situation can be treated as an infinite game, with moves continuing indefinitely; in this

situation, strategies can arise. Surprisingly, however, economists have never treated the game as infinite; this would make the analysis considerably different.

3.11 Collection and analysis of data

Apparently, a critique of the existing literature reveals that there are various different factors which affect manufacturing decisions, and that the decision-making process is complex. Equally, it is apparent that sustainability is an issue of increasing concern which will become more significant in future – as resources depletion becomes ever more apparent – while demand is increasing. Of course, this will affect the transaction costs of firms undertaking their business. Such issues are particularly so where energy and its continued production are concerned. Thus, there are incentives for manufacturers to produce energy efficient appliances, and to also demonstrate this to customers; marketing campaigns are designed to achieve this. There are similar incentives for manufacturers to produce in a more efficient manner, using less energy and raw materials; these incentives will become more dominant as resources depletion becomes more apparent. These incentives will inevitably have implications for transaction costs.

The main contribution of this thesis is the developments to Game theory made herein. In effect, there are two stages to the development of the thesis: firstly, the construction of the model utilising Game theory, and secondly, the analysis of this using data to validate the model constructed. The purpose of the data selected is to verify that the model works, rather than to attempt to refine this model. Accordingly, a relatively small amount of data is needed for this.

For these reasons, the data used in this thesis is restricted to what is necessary to verify the validity of the model. As the model needs to be verified in the context of particular industries – mineral extraction industries – and companies, so this will be undertaken to complete the verification. The data used to achieve this consists of a relatively small amount of public domain data. The selection of these industries and companies is explained and justified below in the sections commencing at 3.17. Inevitably – given the nature of the mining and extraction of minerals – these are global industries and firms, operating in well established markets. It is recognised that reliability and validity of data is essential in order to ensure that the interpretation of results is accurate and reasonable. It is also recognised that, when the data is not sets of quantitative data, then these concepts may not be reliable. In such circumstances, it

is argued that triangulation of data, using differing techniques satisfies the same criteria (see, for example, Lauri, 2011). Naturally therefore, given the nature of data used for verification in this thesis, triangulation of the results obtained from the analysis is also undertaken in order to strengthen this verification process.

Therefore, this research is undertaken to compare the alternative methods of allocating resources and can be depicted by figure 3.3:

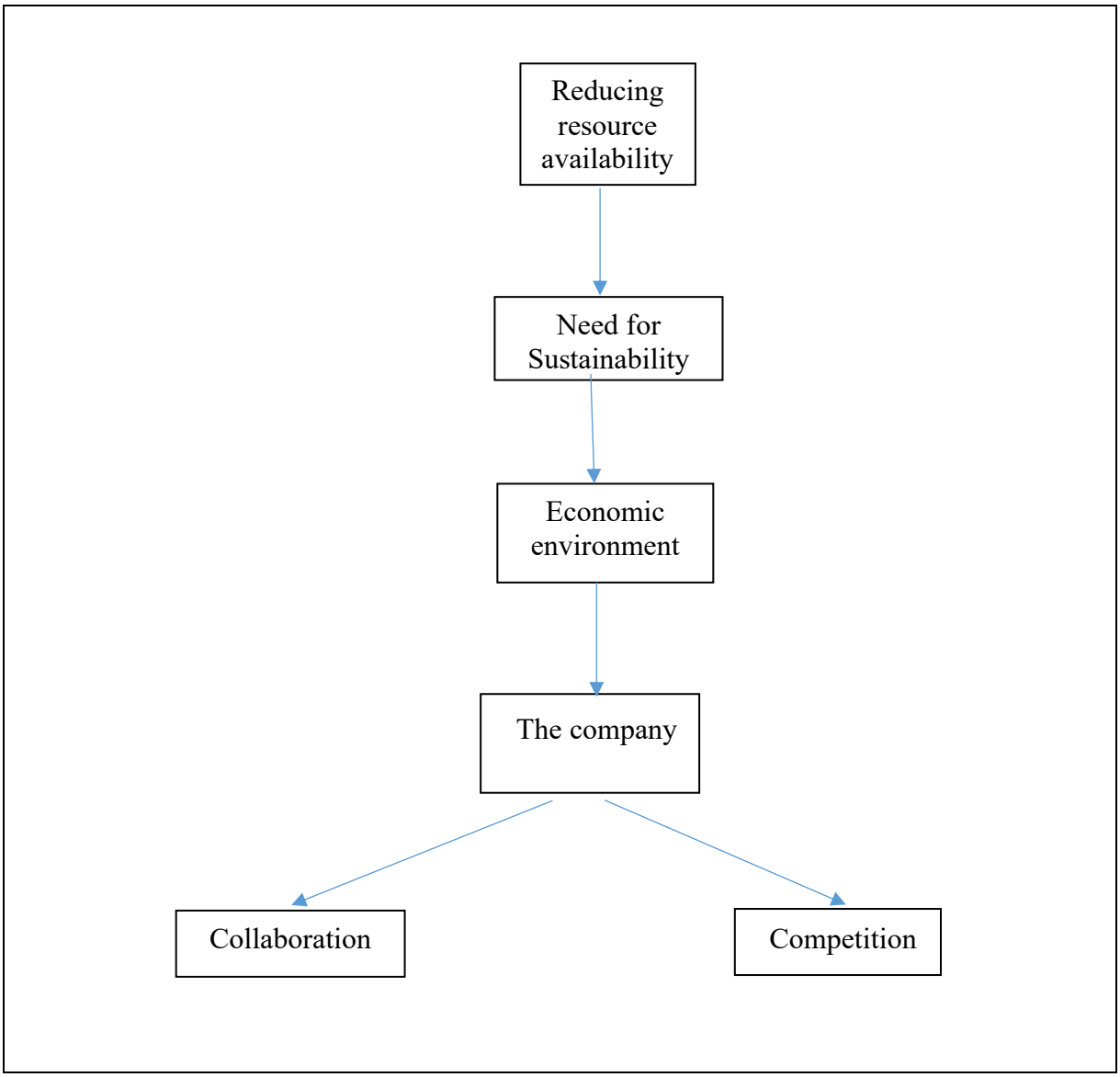

Figure 3.3 – The coming economic environment

3.12 Game theory extensions

In the preceding chapter and explanations above, it has been demonstrated that Game theory is a suitable method for investigating the research problem. Furthermore, it has been shown that little use had been made of the theory for this problem, and that no empirical data had been used in any investigation related to this topic. Consequently, this thesis will make use of Game theory as the principle technique for investigation, and in doing so, new areas are developed.

However, Game theory – as it currently exists – is insufficiently developed, and so the method starts by adding 4 new extensions[38] to the theory:

1. The reducing sum game
2. The application of a mathematical approach to an economist situation
3. The Gaia[39] Game extension
4. The resources' paradox

These are all explained and justified as follows.

3.12.1 The Reducing Sum Game

Some limitations to Game theory instantly become evident when global economy is taken into account and the position of a specific firm in a global economy is assessed (Sassen, 2000), particularly when it comes to current level of understanding regarding Game theory. Game theory effectively categorizes all decisions into two forms, which are non-zero sum and zero-sum. The problem here is that there is an automatic assumption that this would be fine. This is except for the implicit assumption (see Starr & Hol, 1969) that in a non-zero sum game, it is always possible to increase the size of the rewards obtained by the decisions made by the players. The only dissenting voice seems to have been Thurow (1980), who argued that positive outcomes of non-zero sum games were no longer possible, due to high levels of economic growth. However, he continued to argue that competition must therefore become more intense as the only way of gaining benefit. Thus, Game theory assumes that a non-zero sum Game

[38] The names for these extensions have been created in this thesis.
[39] Named in honour of Gaia, the Greek goddess of the Earth – similarly honoured by James Lovelock in his Gaia Theory.

leads to an outcome, which is greater than that possible from a zero-sum game. This is faulty, because currently in the world, the total is not zero-sum, and is not one in which the outcome (i.e. the amount of resources which are available) can be increased. In fact, these resources are reducing in the current environment, described in the preceding chapters, as they are currently being used – or overused – and cannot be indefinitely replenished. Moreover, demand for these resources continues to increase as the world develops. Game theory does not really address this – and so, this is where the main contribution of this thesis is made. This requires the creation of a new game, which is non-zero sum, but also reducing. This extension has been named the Reducing Sum Game.

3.12.2 The application of a mathematical approach to an economist situation

Economists tend not to work with an infinite series of games; conversely, mathematicians (e.g. Davis, 1964) deal with infinite games, but the context is never developed to deal with economic competition. Instead, economists tend to analyse with a very large, but finite, series. This is slightly simpler to analyse, but does not represent the real world, as competition and economic activity is continuous, and therefore effectively infinite. For an analysis of dealing with sustainability, it is necessary that this restriction is removed. For this analysis, therefore, an infinite series (i.e. $n \to \infty$) must be analysed. This is the second extension to Game theory undertaken in this thesis.

3.12.3 The Gaia Game extension

The starting point in this thesis has been taken as a variation of the game with an external regulator (Sanin, 2010); this is a recognised variation of the basic game in which there is the involvement of an external (third) party and the outcome is non-zero sum. In the analysis undertaken here, this third party is being taken as equivalent to a regulator. In effect, the regulator is considered to be a mediating mechanism which enables the market to function, and therefore, the whole global economy to operate (Cebula & Clark, 2014). This applies to both the global economy and to a local market. It is the equivalent of a governance mechanism (see Crowther & Seifi, 2011) by which any market is able to operate.

3.12.4 The resources' paradox

The resources available reduce continuously, as each round of the game is played due to resource depletion. It is played with resources which are less than during the previous round. Under the market system, each player needs to acquire the greatest possible share of the available resources – for maintenance of production and for growth – therefore must compete. This results in an increase in transaction costs, as the firms need to spend more resources just to acquire a diminishing amount of the reducing balance of available resources. At the same time, however, in order to ensure that the size of the collective rewards (i.e. total market) available is as large as possible, this requires collaboration. This means that the competitors are in a situation of both needing to compete and to collaborate at the same time; this is the resources' paradox – a paradox which will continue to exist throughout every round of the game. In order to achieve sustainability, it is necessary for this paradox to be resolved. This need for resolution is at the heart of the Gaia Game extension; mediation will be required for this.

Further explanation and the application of these in context will be shown in Chapter 4.

3.13 Theoretical analysis

Firstly, it is necessary to develop the mathematical model to explain the scenarios and enable comparisons. For this, it is necessary to provide a theoretical analysis which shows that the mathematical calculations are robust. Therefore, this is undertaken to show the effects, over time, of the collaborate or compete alternative strategies. Two further steps are also needed to strengthen the findings from the analysis, and these are undertaken by the methods described.

3.13.1 Linear programming analysis

This theoretical analysis needs to be extended in order to determine the additional mathematical proof which can be derived. This is achieved through linear programming which is used to demonstrate the theoretical robustness of the analysis.

3.13.2 Sensitivity analysis

The theoretical analysis is completed by the development of sensitivity analysis, which shows that the calculations are robust

3.14 Empirical analysis

These mathematical calculations show the theoretical development of the model and its implications. The calculations will be shown to be robust. But a theoretical analysis is, of course, insufficient. This is where previous researchers (e.g. Hirsch, 2009; Schitka, 2014) have finished their analysis. To be certain that the model is robust, it is necessary to undertake empirical calculations making use of actual data. This empirical analysis forms the main part of the following chapters. Then, the implications of this model are discussed more fully, after the analysis has been undertaken.

There are 2 levels of analysis in this thesis – the national or market level and the level of the firm. For a variety of reasons, it is often difficult to separate national and market activity in the control and regulation of these markets, and it is frequently necessary to use national data as a surrogate for market data. This is discussed in subsequent chapters. Thus, empirical analysis for this research needs to be undertaken at these 2 different levels.

Therefore, there are two aspects to the empirical analysis as follows:

3.14.1 Data analysis 1

The first empirical analysis looks at the national level and the effects of the theoretical model at this level. Therefore, this makes use of GDP data.

GDP data is produced by all countries, and is put into the public domain. There are a number of supranational organisations which collate this data and make it freely available. Examples of such organisations include the International Monetary Fund (IMF), the World Bank, and the World Trade Organisation (WTO). Such data is considered to be primary data, and is used in research by economists, political theorists and finance experts. For this thesis, the World Bank data is used.

3.14.2 Data analysis 2

At the second level of analysis, it is necessary to perform the same calculations at the level of the firm within an industry. The only appropriate method for doing so is to look first at data for the industry as a whole. Thus, data for all the firms in the industry in total is needed for this analysis, in order to calculate the cost of regulation for that industry as a proportion of total costs. Cost of regulation is defined as the costs associated with administering, whatever rules are being applied regarding pricing and distribution of the mineral. These are set by governments, international bodies and others according to particular circumstance. They can be categorised as additional administration costs for any firm. For some industries, such information is available in detail through a trade association. For others, just the overall size of the industry is available from such a source. In all cases, the actual cost of regulation as a proportion of total costs is not shown in any publicly available financial reporting, and thus needs to be interpolated. The process of doing so is explained in chapter 5.

Additional information is needed to perform a similar analysis for individual firms, and these too need to be interpolated from the publicly available data. For each firm used in this analysis, the published accounts are used to extract financial data. This is data which is used by economists, accountants and finance experts for undertaking research. For all major firms, this data is publicly available, as all firms listed on major stock exchanges are required to make this data publicly available. Moreover, all firms – as they are seeking inward investment – find it beneficial to make this data publicly available (Lansbury, Pain & Smidkova, 1996). Thus, for this second part of the empirical calculation, a number of firms within each of the industries are selected for verification and the model is analysed for effectiveness. The firms selected are the largest firms in the industry with the exception of Chinese firms, who report differently and do not report in English. This is explained further in chapter 5.

3.14.3 Modelling the analysis

This analysis and the data used can be represented by the following model:

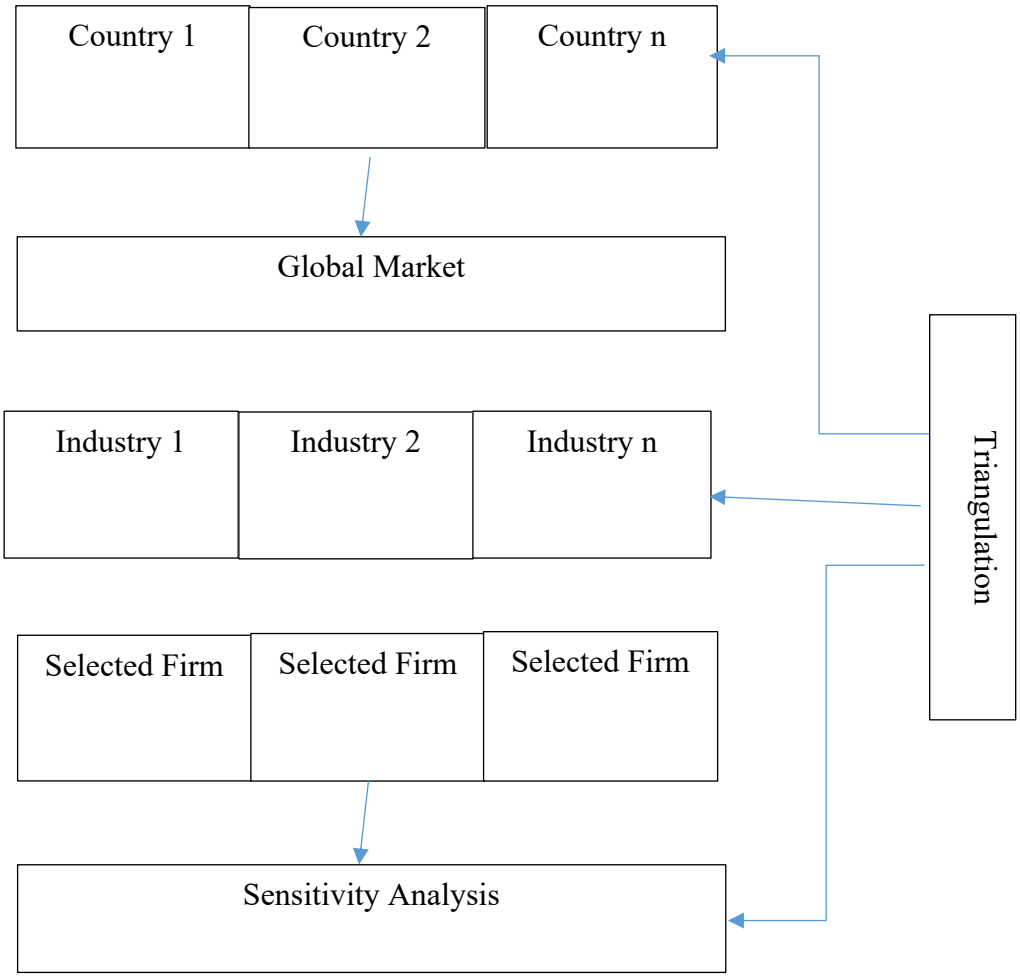

Fig 3.4 – Model of data analysis

3.14.4 Primary data

According to Saunders, Lewis & Thornhill (2000), primary data forms the main method of collection of data, but that this is not necessarily superior to secondary data. In simple terms primary data is collected by the researcher, while secondary data has been collected by another. Most researchers would agree with Malhotra (1993) that secondary data is equally valid, as the strength of the research is based upon how the data is used empirically rather than its source. Indeed, many researchers (e.g. Smith, 2011) would argue that financial data can actually be considered to be primary data. It is for this reason that economic and finance calculations are based upon such data – classed as either primary or secondary – sources, and make use of financial data which has been collected for the legal requirement of annual reporting – in other words, the published annual reports. This thesis adopts the same approach.

3.15 Rationale for selection of data levels

It needs to be empirically verified that the model developed is robust, and therefore, shows whether the competitive approach or the collaborative approach is better both for the planet - and therefore for society at large and all its stakeholders - and for individual firms within any industry. Therefore, it is necessary to consider this at two levels - a societal level and at the level of individual firms. At a society level, the only realistic way to do this is to look at countries as representing society at large. For individual firms, it is necessary to look at individual industries and firms within those industries.

Of course, the collaborative model of economic activity does not exist at the present, and so it is necessary to select data which represents this. Fortunately, such data is available within the public domain. Such data is the data concerning gross domestic product (GDP) and gross world product (GWP), which is produced by the United Nations (UN), the International Monetary Fund (IMF) and the World Bank (WB) on a regular basis. The actual figures differ between them and the differences and reasons are discussed in chapter 5.

In 2015, the GDP of the largest countries were:

Country	$ trillion
China	19.4
EU	19.2
USA	17.8
India	8.0
Japan	4.8
Germany	3.8
Russia	3.7
Brazil	3.2
UK	2.8
Indonesia	2.8

Table 3.1 – Gross domestic product of the largest countries
(source http://statisticstimes.com/economy/countries-by-gdp.php -based upon IMF data)

It should be noted that these figures are only estimates and can be subject to revision. This is due to the margin of error involved in the production of these figures. It is important to observe that each country produces its own calculation of its GDP (and revisions) and publishes this in the public domain. Then, these three bodies referred to above seek to make comparisons by making adjustments to these figures before their own publication.

This illustrates one of the problems in the calculation of GDP, which is that these calculations are subject to inaccuracies in reporting and to statistical error. The overall size of these errors is – to a large extent – unknown, but the USA government[40] states that they always revise their GDP information at least twice after publication, while the UK does so several times without being specific. It is generally considered that some countries misreport their GDP for political reasons – again, to an unknown extent. In the UK, it is estimated that the error runs at slightly in excess of 2%[41]. Blades (1980) has conducted a study, which shows that the average margin of error is about 3% amongst all countries. Various authors have attempted to calculate the margin of error for individual countries (e.g. Cerqueira et al., 2009 for Brazil; Aruoba et al., 2013 for USA; Mitchell et al., 2005 for UK), but no global calculation has subsequently been made, although Fischer et al. (2009) discussed the margin of error in the context of forecasting global energy demand.

3.16 Selection of countries for analysis

It is argued that three countries are sufficient to allow for variety and triangulation. Thus, three different countries have been selected, with only one of them being amongst the top 10 in size of GDP. The other two are different in size, location and nature. Thus, the three countries selected are:

UK
Iran
Malaysia

[40] http://www.usgovernmentspending.com/percent_gdp accessed 21/5/2017
[41] https://www.ons.gov.uk/economy/grossdomesticproductgdp/bulletins/grossdomesticproductpreliminaryestimate/januarytomarch2016 accessed 21/5/2017

These countries have been selected for their diversity and also for personal reasons. Nevertheless, some brief detail of the nature of the countries is needed in order to explain the rationale for their selection.

- **UK**

The UK is the eighth largest economy in the world with a GDP of $2.8 trillion and a per capita GDP of $42,000. It has a population of 64 million with a life expectancy of 81 years. The UK is a developed country - one of the first to achieve this status and one of the largest economies, despite its relatively small size. It was the world's first industrialised country, having led the Industrial Revolution[42].

Like many developed countries in the West, the reliance upon raw materials for production is declining, as the nation concentrates more upon high value technical developments and the finance industry. Nevertheless, power remains a priority, and access to productive capacity is important. So, the UK is the largest producer of oil and second-largest producer of natural gas in the European Union, but after many years of being a net exporter of both fuels, the UK became a net importer of natural gas in 2004, and of crude oil in 2005. Production from UK oil and natural gas fields peaked in the late 1990s, and has declined steadily over the past several years, as the discovery of new reserves has not kept pace with the maturation of existing fields. Currently, the government is seeking to increase capacity through the development of shale oil fields and the development of renewable energy capacity – chiefly wind, sunlight, waves and hydropower.

Originally, the rapid development of industry in the UK was based upon access to power and to raw materials, together with technological developments by its engineers. Originally, the power used for its development was water power from its many rivers. Later, coal and subsequently electricity provided the necessary power. Its rapid development led to the exhaustion of the limited supplies of many raw materials - principally metals - and the UK became one of the first countries to face the problem of depleted resources, forcing it to seek alternatives. The immediate alternative was global conquests which gave it access to the needed

[42] Data sourced from the World Factbook (https://www.cia.gov/library/publications/the-world-factbook/)

resources from other parts of the world. This has been coupled with continued technological leadership and development to address the problems of resource depletion.

- **Iran**

Iran has a GDP of $388 billion and a per capita GDP of $4,900. It has a population of 79 million with a life expectancy of 74 years. From 2006 until 2015, the country was under sanctions imposed by the UN, and this certainly hindered development[43]. From the time of the Islamic revolution, sanctions had been imposed against Iran by the USA government, and these were extended in 1995 against firms trading with Iran. Although the UN sanctions were relaxed in 2015, the US sanctions have not been relaxed; this is currently hindering Iran's development after the relaxation of sanctions, as firms are reluctant to incur the wrath of the US government. This reluctance applies especially to financial and banking institutions, and Iran is not yet connected financially with the rest of the world, which is of course hindering its development. So, Iran is currently in the situation of not being under sanction[44], while still having the effects of sanctions imposed on it.

Owing to its vast area, Iran is benefited from diverse climatic conditions. It means that while people in the north parts wear winter clothes to protect them against cold and snow, people in the south are sun-bathing or swimming at Persian Gulf. Despite the limiting of development due to sanctions, Iran is nevertheless a powerful country, which is dominant in the Middle East and vies with several other countries (principally Turkey and Saudi Arabia) for leadership. Iran is OPEC's second-largest oil producer and the fourth-largest crude oil exporter in the world[45]. So, it has the potential to become a world energy superpower, as its production is coupled with vast reserves estimated to be 10% of total world reserves. This is due to the nature of the Islamic state government without the political uncertainty of many oil producing countries. Of course, Iran exports most of this oil and the revenue received (currently, around 50% of the government total budget) makes the government very strong and able to engage in many projects without any need to tax its citizens.

[43] Data sourced from the World Factbook (https://www.cia.gov/library/publications/the-world-factbook/)
[44] Currently, however, the Trump administration has reimposed sanctions, although the rest of the world has not followed suit, so it would still be appropriate to state that the effects of sanctions are being felt.
[45] http://www.eia.doe.gov/cabs/Iran/Oil.html accessed 12/12/16

The economy of Iran is the 16th largest in the world when measured by purchasing power parity. This economy is a mix of state ownership and central planning for the oil industry and many other large enterprises, combined with a large number of very small, and often village-based enterprises and small-scale private trading and service ventures. Iran is both developing and urbanising rapidly, with over 60% of people currently living in cities, and a projection that this will rise to 80% in the next 15 years.

Through the market reform plans, Iran is intending to diversify its oil-reliant economy. Other forms of industry developed in Iran include biotechnology, nanotechnology and pharmaceuticals. Over the past 15 years, the government have placed an emphasis on the local production of domestically consumed goods such as home appliances, cars, agricultural products and pharmaceuticals. Consequently, it is the leading manufacturer in the Middle east for the production of motor vehicles and transportation, construction materials, home appliances, food and agricultural goods, armaments, pharmaceuticals, information technology, power and petrochemicals. Therefore, it is in a unique situation which makes it suitable to use in the verification of the models developed.

- **Malaysia**

Malaysia has a GDP of $313 billion and a per capita GDP of $10,500. It has a population of 31 million, with a life expectancy of 75 years[46]. The government has ambitiously set a target to achieve the status of a developed country by 2020 – which is interesting, as there is no precise definition of a developed country other than consensus. However, the World Bank[47] identifies it as a country with high income inequality compared to developed countries. It has had severe racial problems, which are carefully suppressed after the racial riots of the 1970s, but seem to be on the rise again.

Malaysia is considered to have one of south-east Asia's most vibrant economies[48], which is a result of the long period of political stability and related economic growth. It consists of two regions, which are separated by just over 600 miles of the South China Sea. It is a multi-ethnic, multi-religious federation of 13 states and three federal territories. The country has benefitted

[46] Data sourced from the World Factbook (https://www.cia.gov/library/publications/the-world-factbook/)
[47] www.worldbank.org/en/country/malaysia/overview accessed 12/12/16
[48] www.bbc.com/news/world-asia-pacific-15356257 accessed 12/12/16

from a growth in manufacturing, and is a major tourist destination. It is a significant net exporter of oil and the second largest exporter of liquefied natural gas (LNG) in the world behind Qatar. It has the third highest oil reserves in the Asia-Pacific region after China and India. The oil industry is dominated by the state-owned company – Petronas – which is also the largest contributor to government revenues. Petroleum and tin are the two mineral resources, which are most significant to the Malay economy. Its position as a developing country makes it a suitable country to study, alongside the other two described above.

3.16.1 Personal reasons for choice of countries

The three countries vary in size, although none are extremely large or small. They vary in level of development, but have some similarity in terms of production base and mineral extraction experience. These make them suitable exemplars to test the models developed. Additionally, there are personal reasons for my choice of these three countries. Currently, I am resident in the UK but I am a native Iranian and lived in Iran for most of my life. However, before coming to the UK, I lived in Malaysia for a number of years. Therefore, I have an interest in these three countries and a considerable amount of background knowledge of them, which also makes them suitable for my evaluations.

However, it is considered that the exact choice of countries is largely irrelevant, as the results of any analysis would not be changed by selecting different countries.

3.17 Selection of industries for analysis

As explained above, it is necessary to look at data from some individual companies as well as for countries in order to test the model. In order to look at companies, it has been decided to look at the data within four industries - industries which are important to the economies of the countries, and for which resource depletion is an issue. This means looking at some extractive industries. The four chosen are:

- The oil industry;
- The tin industry;
- The lead industry;
- The copper industry.

The context in which all four industries have been selected is explained below. The principle on which selection of individual companies was made is explained above (section 3.14.2), while the individual companies are detailed in chapter 5 when the analysis is undertaken. Oil has been chosen because the significant factor for this mineral is the extraction rate rather than total reserves, and many consider that the maximum rate of extraction is nearly reached. The other industries have been selected because the evidence shows that they are nearing exhaustion. However, it is again argued that the actual choice of industry will make no difference to the analysis.

3.17.1 The oil industry

The oil industry is very large and important. Thus, it is an industry which is more subject to government regulation and control than are others. Primarily this is to protect national interests as oil has been used as a political and economic weapon of states. The companies involved in oil tend to be very large companies, and by the nature of the industry, tend to be international companies. The largest (by market capitalisation) in 2015 are:

	Firm	Revenue (1000 million dollars)	Country of domicile
1	Saudi Aramco	478.0	Saudi Arabia
2	Sinopec	455.5	China
3	China National Petroleum Corp	428.6	China
4	PetroChina	368.0	China
5	Exxon Mobil	268.9	USA
6	Royal Dutch Shell	265.0	Netherland / UK
7	Kuwait Petroleum Corp	251.9	Kuwait
8	BP	222.8	UK
9	Total SA	212.0	France
10	Lukoil	144.2	Russia
19	Petronas	100.7	Malaysia

Table 3.2 – Details of the biggest oil producing companies
Based upon data sourced from https://www.offshore-technology.com/features/largest-oil-and-gas-companies/

As far as production and reserves are concerned, then the largest company is Saudi Aramco with production at a level of almost double the second in size, NIOC[49] - the nationalised oil company of Iran. It is an industry which is important to all three countries being examined, with Iran being one of the largest producers in the world[50]. Malaysia is the 26th in production and Petronas – its national oil company – is one of the top 20 largest in size. The UK is much less significant in terms of domestic production, but its companies are some of the biggest in the world. Oil is also of great significance to the world economic system and something which

[49] The Nationalised Iranian Oil Company
[50] Currently, it ranks 5th, but is increasing its output as sanctions have been relaxed, and it is using the revenue for development of the country - something which was hindered by the sanctions.

is affected by resource depletion. This is despite the effects being lessened by the new technologies which enable its extraction from deep undersea and from oil shale areas.
The oil industry is a politically and economically sensitive industry (Kleveman, 2004), and tends to be controlled quite closely by the governments concerned. Such control and regulation takes place at a national level, partly because it is a source of tax revenue by most governments, as well as a significant influence upon economic health. For this reason, a precise cost of regulation is impossible to establish, primarily because costs are associated with tax revenue rather than regulatory oversight.

In addition to such governmental involvement, there are also a large number of trade associations. Some of these represent the interests of the companies in that country while others claim to represent the regional interest and influence. Examples include:

Association	Web address	Country
World Petroleum Council (WPC)	www.world-petroleum.org	UK
American Petroleum Institute	www.api.org	USA
European Petroleum Industry Association (EUROPIA)	www.europia.com	Belgium (EU)
European Fuel Association	www.eurofuel.eu	Belgium (EU)
Union of European Petroleum Independents (UPEI)	www.upei.org	France
The Norwegian Petroleum Industry Association	www.np.no	Norway
Oil and Gas UK	www.oilandgasuk.co.uk	UK
United Kingdom Petroleum Industry Association (UKPIA)	www.UKPIA.com	UK
Global oil and gas industry association for environmental and social issues (IPIECA)	www.ipieca.org	UK

Table 3.3 – Trade associations for oil production
Extracted from https://apea.org.uk/pages/contacts/industry-associations

An international body of regulation does not exist for this industry, but there is a range of trade associations operating at a national or regional basis, as table 3.3 shows. This means that no figures for international costs of regulation exist, and most other bodies are designed to protect national interests, especially in the form of tax revenues. Thus, a true figure for regulation does not exist.

3.17.2 The tin industry

Like most extractive industries, the tin industry is dominated by a small number of large international companies. Increasingly, the Chinese play a significant and increasing role in the extraction and processing, but it is almost impossible to obtain accurate financial data from such companies, and so they are excluded from the analysis undertaken. Nevertheless, the metal remains important, and therefore, this is a suitable industry in which to test the model developed with real data.

Tin was a major industry in the UK, with mining being predominantly in Cornwall until supplies were fully extracted in the early 20th century. As supplies diminished, Cornish miners moved to elsewhere in the world, and founded mines in what is now Malaysia. Kuala Lumpur was established on tin, and this metal is still an essential resource for Malaysia which encompasses one of the world's greatest extractors of tin. There is no significant history of tin being mined in Iran from any period until the present, but as civilisation was first developed there more than 5000 years ago, it was an important metal and was imported from elsewhere in that region. It is important to note that tin represents an essential product with only a small number of large firms, which effectively constitute self-regulation for the whole industry. Therefore, the real data from tin industry would be ideal for testing the model.

Tin is one of the metals first extracted by human, which led to the development of the Bronze Age more than 5000 years ago – so it has a long history. Nowadays, the primary use of tin is for producing solder and plating steel and iron with tin which makes a desirable finish. Other applications of tin include production of alloys such as bronze and pewter and alloy die-casting. Besides, modern engineers use this metal for enhancing machinability of tungsten.

Annual production in 2014 was 345,800 tonnes, reduced from 383,500 tonnes in 2011, of which 83% was mined in Asia and just over 50% was used to manufacture solder. According

to the USGS Minerals Commodity Summary (2018)[51], the annual production of tin was 290,000 metric tonnes, with world reserves standing at 4.8 million metric tonnes. On this basis, supply will be exhausted by 2034 – in the near future.

Such raw materials as tin are increasingly being assessed by investors and legislators on the basis of three aspects of sustainability: economic growth, contribution to society, and protection of the environment.[52] Increasingly, such factors are of significance to consumers. This growing importance has been recognised by the tin industry, which has therefore introduced long-term plans, aiming to demonstrate the positive contributions made by tin towards development. Thus, tin production is related to all three aspects of sustainability. Also importantly, the mining activity involved provides a livelihood for many thousands of miners, their families and ancillary workers in developing countries in which raw materials are mainly located. These locations account for about 98% of total world production. Similarly, this mining also stimulates development in these countries through tax revenues earned, and through export earnings, and by the support of the companies involved in investment in transport and other infrastructure. Additionally, most companies involved in mining and smelting also have a commitment to corporate social responsibility programmes and the rehabilitation of the land used after extraction, if completed. For the mineral itself, increasing scarcity is becoming apparent and consequently, recycling plays a growing role, so now over 30% of tin used is produced from the secondary refinement of tin and alloys. Therefore, it can be argued that products containing tin have also contributed to quality of life (Collingham, 2017), including a number of existing and new applications connected to health and energy-saving benefits.

Just as for the oil industry, there is no international regulatory organisation for the market. However, there is a trade association – ITRI[53] – which claims to fulfil this function amongst others. According to the Companies Register in the UK:

> "ITRI Limited is an Active business incorporated in England & Wales on 24th November 1994. Their business activity is recorded as Support Activities For Other Mining And Quarrying. ITRI Limited is run by 10 current members. It has no share capital. It is also part

[51] https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/tin/mcs-2018-tin.pdf accessed 21/7/2019
[52] https://www.itri.co.uk/index.php?option=com_zoo&task=item&item_id=2717&Itemid=143 accessed 13/12/16
[53] ITRI = Industrial Technology Research Institute.

of a group. The latest Annual Accounts submitted to Companies House for the year up to 31/12/2011 reported 'cash at bank' of £2,994,518, 'liabilities' worth £1,647,196, 'net worth' of £3,376,255 and 'assets' worth £4,138,736. ITRI Limited's risk score was amended on 29/03/2013".

3.17.3 The lead industry

Britain was an important source of lead for over two thousand years, until reserves became exhausted in the nineteenth century. Indeed, it was so important that it had its own laws regarding extraction and ownership of mines (Ford & Rieuwerts, 1983). At that time, lead mining was so important (alongside tin mining) that it caused the invention of the steam engine by Trevithick, which was invented to pump water from the mines. Originally, the ore extracted was galena (PbS) (Kiernan, 1989), but as supplies became exhausted, increasingly sphalerite (ZnS) is extracted around the world. Sphalerite is principally zinc mixed with lead, and their separation is a complex process which leads to 99% pure zinc and lead[54]. Lead is less used now because of the poisonous effects it has, so the principal mineral extracted is zinc, with lead almost as a by-product.

Originally, lead was used extensively, because it was easy to work; it was used for such things as roofing and water pipes. Modern uses are mostly in the production of batteries (80% of total usage)[55] and ammunition, along with its use in glass manufacture. Therefore, it still remains an important raw material for manufacturing. Currently, the largest countries for production are as listed in table 3.5:

Country	Percentage of production
China	52%
Australia	12%
USA	7%
Peru	5%

Table 3.4 – The major lead producing countries
Extracted from https://www.indexmundi.com/minerals/?product=lead&graph=production

[54]http://www.williamhunter.co.uk/ZINC/relationshipznpb.htm accessed 14/12/16
[55]http://www.ilzsg.org/static/enduses.aspx?from=2 accessed 14/12/16

This will probably change as Iran continues its development, as this country has the 14th largest reserves with 5% of the world total. Currently, Iran holds 7% of total world reserves of minerals but they are underused, contributing less than 1% of total GDP[56]. According to the USGS Minerals Commodity Summary (2018)[57], the annual production of lead was 4.7 million metric tonnes, with world reserves standing at 88 million metric tonnes. On this basis, supply will be exhausted by 2037 – in the near future.

It can be seen that lead is a less important mineral than it was previously, but is still in significant demand in developed countries for a variety of purposes. Compared to oil, it is a fairly small-scale mineral, but still of sufficient significance to make it a suitable industry to use for the evaluation of the models developed.

3.17.4 The copper industry

Copper has been mined by humans for about 8000 years and has been used extensively ever since. It is an essential trace element that we all need in our diet (US National Library of Medicine)[58]. Apart from its use in coinage, it is primarily used currently in electrical equipment, due to its low resistivity.

The leading copper producer in the world is Chile, producing an estimated 5.8 million metric tonnes of copper in 2017. In second place is Peru, with an estimated production of 2.4 million metric tonnes in 2018. The world's third largest is China, which produced an estimated 1.6 million metric tonnes of copper in 2018[59]. According to the USGS Minerals Commodity Summary (2018)[60], the annual production of copper was 19.7 million metric tonnes, with world reserves standing at 790 million metric tonnes. On this basis, supply will be exhausted in about 40 years.

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[56] https://en.wikipedia.org/wiki/Mining_in_Iran accessed 14/12/16
[57] https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/lead/mcs-2018-lead.pdf accessed 21/7/2019
[58] https://medlineplus.gov/ency/article/002419.htm accessed 23/7/2019
[59] https://www.statista.com/statistics/264626/copper-production-by-country/ accessed 23/7/2019
[60] https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/copper/mcs-2018-coppe.pdf accessed 21/7/2019

3.17.5 Significance of choice

It is accepted that the projected exhaustion dates are not fixed and are subject to considerable debate. It is also accepted that world reserves are subject to increase, as more deposits may be discovered and recovery technology becomes more efficient. Nevertheless, the data discussed in chapter 2 – regarding impending exhaustion of availability of minerals – suggest that there is an impending crisis which needs to be considered – if not now, then in the near future. It is also accepted that a different choice of minerals to investigate would show different extinction dates. However, it is argued that any different choice would not affect the verification of the model, which is independent of minerals chosen.

3.18 Chapter summary

This chapter has considered the research paradigm adopted, and has explained the research methods which will be undertaken, and has produced a flow chart to explain this process. Thus, an ontological position has been developed, along with a complementing epistemological position and appropriate associated methodology; this is primarily grounded in positivism. The chapter has explained what theoretical developments will be made in the development of a model. This is followed by an explanation of what empirical data will be used to test the theoretical developments, and of the levels of analysis which are necessary in this testing. The nature of this data and the context in which it has been selected are also explained and justified. This will all be developed further in the following chapters.

Chapter 4
Theoretical Development

4.1 Introduction

It has been shown in preceding chapters that mineral resources are finite in quantity and becoming depleted. Therefore, the issue to be investigated in this thesis is how to make best use of available resources. It has further been shown that Game theory is an appropriate method for such investigation, and that this has not previously been investigated by this method in a global context. In more local contexts, Caddy & Agnew (2004) consider marine resources, while Sonter et al. (2014) consider the effects of mineral exhaustion upon changing land use which lead to different conclusions being drawn. In this chapter, this is explored by building a model which will be evaluated in subsequent chapters.

4.2 Supply – Demand Equilibrium

The supply of any mineral is affected by a number of factors:

- The quantity remaining to be extracted. At the moment, there seems to be a sufficiency of every mineral to meet demand; at some point, the amount available can be expected to decline. As the quantity declines, then there is a corresponding reduction in production capability.
- Technological factors which affect the efficiency of extraction. Technological changes can be expected to continue to increase the efficiency of the extraction process.
- The amount of the mineral available for recycling. Generally, the amount of any mineral which is being recycled is increasing, but it will never be the case that all of any mineral can be recycled.
- The availability of substitutes. This is an unknown as technological development may well make a significant difference to demand, and probably reduce the demand for any particular mineral.

Thus, supply can be modelled as:

$S = Q – T – R – E$

Where

S = supply available;

Q = quantity to be extracted;

T = technological changes;

R = recycled quantities;

E = effect of substitutes.

Similarly, the demand for any minerals is affected by a number of factors:

- Production requirements. Generally, this means that as production of any finished product increases, then demand for the raw material increases proportionally; thus, demand for any mineral is increased accordingly. In effect, this can be equated to increase in GWP.
- Technological changes. Any such changes can affect (and probably lower) the amount of any mineral required for incorporation into a product
- Fashion and popular opinion. Changes in fashion or popular opinion can increase or decrease the need / wish for any product, and hence, its production requirements. For example, at the moment, the demand for plastic is being revised as problems are exposed.[61]
- The development of substitutes. As substitutes become available for any product, then this can be expected to reduce demand for any mineral inputs.

Thus, demand can likewise be modelled as:

$D = P - T \pm F - S_a$

Where

D = demand;

P = production of finished goods;

T = technological changes;

F = changes resulting from fashion;

S_a = substitutes available.

[61] See www.unenvironment.og/interactive/beat-plastic-pollution accessed 25/1/20

Of course, equilibrium is maintained through the market and the price mechanism, so that:

$D = S$

The evidence from the preceding chapters has shown that demand has continued to rise over time, and therefore, supply has similarly increased. It is accepted that some stockpiling is occurring (as a normal part of business to deal with shortages) and that this will affect the supply demand equation in the short term; it is argued, however, that it has no long term impact and does not, therefore, affect the argument here. Given the finiteness of supply of each mineral, there is an obvious imperative to increase supply and reduce demand. In effect, this means that technological changes to reduce need for the mineral become more important as does the effect of substitutes. Thus, if supply cannot be increased due to depletion and imminent exhaustion, then the only alternative would be to reduce demand, which would require a reduction in production of goods made from the mineral. Therefore, there are many ways in which either supply or demand could be altered by a number of factors; it remains constant that the supply of any mineral is finite and absolute. Hence, this thesis is concerned with the way in which this availability can be best used for the sustainable benefit of the plant, and hence, examines alternative methods of distribution. On that basis, none of these changes will affect the optimum method of distribution; optimal distribution is not dependent on methods of creating supply and not dependent upon demand except when price is the method of allocation. As discussed in section 3.5, optimal distribution depends on utility and not price, when sustainability is based upon restricted resource availability.

4.3 Optimising distribution

The use made of any particular mineral is dependent upon the demand for that product, and therefore, it follows that if demand is reduced, then the availability of supply becomes less critical. In a situation in which supply is constrained and cannot readily be increased, then demand is really primarily based upon two factors – the quantity of finished goods able to be produced and availability of substitutes. Any excess demand cannot be met, as no more mineral is available. Obviously, supply can be increased until the mineral is exhausted, but increasing supply in the present shortens the time until availability ceases to exist, and this leads to unsustainability. The other factors mentioned above are relevant but less significant in effect and none of these affect optimal distribution. Finished products required depend upon the

economic growth of the world: as shown in chapter 3, GWP doubled between 2005 and 2010 and doubled again between 2010 and 2015. There is every reason to think that GWP (i.e. economic activity) will continue to increase, and therefore, that demand will continue to increase for minerals required in production.

The question of the availability of substitutes is more complex. Over time, technological development means that less of any mineral tends to be required in the manufacture of any product. Such development also tends to mean that products themselves change, with some being no longer required. Equally, new materials are invented or new uses for a material discovered. Of course, one such example which has been used as a substitute for certain minerals is plastic. This has been used quite extensively, but more recently, concern has been raised about its long-term effect and the ability to recycle or reuse plastic (Hopewell, Dvorak & Koslor 2009). Another case where substitutes are becoming common is in the energy industry, where coal and oil have been – to an extent – superseded by alternatives such as solar energy, hydro energy and atomic energy. Renewable energy resources have increased dramatically such that production rose by 40% between 2010 and 2016. However, total world demand also rose dramatically so that renewables only increased from 19% of total production to 22%, and of this, two thirds was from hydroelectricity production (https://ourworldindata.org/renewable-energy). Between 2010 and 2016, world electricity production has increased by 6%, while the proportion from traditional fuels has decreased by 5%, primarily due to a reduction in coal consumption. As a result, demand for oil has not really been affected (Sadorsky, 2009). At the same time, concern has been expressed about the environmental effects of hydroelectricity production and the deltas surrounding dams (Guo et al., 2007).

Therefore, the evidence suggests that substitutes are not alleviating the demand for minerals, and that this demand continues to increase as world economic activity continues to increase. Therefore, given the finiteness of supply, it becomes apparent that sustainability requires the best use of available minerals, and that the consideration of how to ensure this distribution is a pertinent question and worthy of research. On this basis, therefore, the thesis continues by building a model to explore this using Game theory.

4.4 Developing Game theory

In order to use Game theory to investigate this problem, it has been argued – in the preceding chapters – that the theory has not yet been utilised to address the problem of resource depletion on a global scale. However, a few (e.g. Acemoglu et al., 2012) have considered the likelihood of war caused by competition for scarce resources. None have considered any effect upon the economic model of firms' competitive behaviour. Nevertheless, it has been generally accepted that the Prisoners' Dilemma has become a fixed part of the repertoire of economic and social behaviour (e.g. Sen, 1973; Sibley & Tisdell, 2018), to such an extent that it is treated as a common sense approach to economic analysis. Equally, it has been used to model the behaviour of states in international negotiations (Grieco, 1988; Barrett & Dannenberg, 2012). Therefore, it provides the foundation for analysis in this chapter and the whole thesis. Nevertheless, it is true that some aspects of the theory have not been developed to deal with the issue of resource depletion and sustainability, the topic of this thesis. Indeed, it is argued here that current theory is inadequate, and so, the development of some extensions is necessary.

4.4.1 The Extensions

As stated in section 3.12, four extensions are needed to be developed:

- The reducing sum game;
- The application of a mathematical approach to an economist problem;
- The Gaia Game extension;
- The resources' paradox.

4.4.1.1 The Reducing Sum Game

If the game is not zero-sum, then the total amount to be divided by the parties to the game can change, and this gives the players an incentive to both increase their share and also to take actions which will increase the total amount available to be divided. This can equate to conspiracy between firms, as described by Adam Smith (1759), and leads to the existence of cartels. It differs from the tragedy of the commons (see Hardin G, 1968) because conspiracy

and the existance of cartels implies the creation, through collective action, of an increased amount of reward - exploitation of the purchaser for the suppliers' benefit. On the other hand, the tragedy of the commons implies the selfish overuse of communal assets without regard to any effect upon others.

Therefore, in a non-zero sum Game, there will exist conflicting motivation towards both competition and collaboration. However, the dominant strategy will always be the one which results in a Nash equilibrium and tends to lead to a strategy based upon a competitive approach (Minas et al., 1960).

In zero-sum games however, the situation is different, and the strategy of collaboration tends to dominate as the series of games increases in number. Therefore, it appears that a collaborative strategy is the optimum strategy for most situations, which poses a question as to why the dominant strategy in our market led economy is essentially a competitive one despite various calls (e.g. Hamel, Doz & Prahalad, 1989; Chetty & Wilson, 2003; Hartley et al., 2013) for collaboration in particular circumstances, but no calls for general collaboration. However, Oliver (2004) has suggested that an understanding of the competition and collaboration duality can yield benefits in certain circumstances, albeit of a short-term nature for particular purposes.

It can be observed that strategic decisions – both by governments and by companies – tend to one of the extremes – either towards always competitive or towards always collaborative (Axelrod, 1984). Indeed, one of the features of Game theory analysis, as applied in such situations, is that it mitigates against any combination of strategies, and favours the poles as decision (Luce & Raiffa, 1957); a number of situational reasons (Lee, 2008) have been suggested as to why this might be so. However, in any situation, the outcome is the sum of the actions: always 1 in a zero-sum Game, and assumed to be possibly greater than 1 if the game is non-zero sum. This is because the economic system of the world is based upon growth as both possible and desirable, with that growth being determined by the decisions made by the players involved in the game. And this presents a problem, as it is unrealistic in the current world where resources are depleted and overused, such that it is doubtful if even current levels of activity can be maintained into the future. In this situation, the players themselves are contributing by their decisions to a reduction in the level of resources available to be used. This is the revised argument of Lovelock (1979, 2006), who now holds that the resources of the planet have been overused beyond the ability of the earth to heal itself. Thus, it is necessary to

redefine a non-zero sum Game in the modern global economy as one in which total possible outcomes are reducing – because of the actions of the players – and cannot be increased, as there are no more to be had. This is a distinct move from current thinking concerning Game theory in this area, but needs to be considered fully in the context of this thesis.

4.4.1.2 The application of a mathematical approach to an economist situation

In developing the theory and its extensions, it is helpful to start from first principles. The basic zero-sum Game is depicted as:

$\sum = ab + (1-a).b + a.(1-b) + (1-a).(1-b) = 1$

Game basics:
a, b = outcomes from competition
A, B = parties involved

		B
	ab	b(1-a)
A	a(1-b)	(1-b)(1-a)

The starting point is this basic game which is the zero-sum game. Here, the outcome is divided between A and B depending upon the strategies they decide to adopt. It is significant that the players can only affect the division of the outcome but not the overall sum. When there is only one round of the zero-sum Game, the players can benefit themselves most by competing, as shown:

For a one round game:

$ab > (1-b)(1-a)$

However, when the game is part of a series, this changes, and the best outcome for each partner is to copy the strategy chosen by the opponent in the previous round (Brams & Straffin, 1979) For a continuing series such as for companies operating in the market, the number of rounds is effectively infinite (i.e. $n \to \infty$). In effect, this means that the two competitors – combined – get the best result, if they adopt a strategy of collaboration:

$\sum_{n\to\infty} ab < \sum_{n\to\infty}(1-a)(1-b)$
Where n = number of rounds in the series.

4.4.1.3 These extensions in practice

When the Prisoners' Dilemma Game is applied to companies in a business situation, although both strategies of competition and collaboration – or even a mix of the two strategies in successive rounds – can be adopted, there is inevitably a tendency towards the extremes, with just one of the strategies chosen all the time by each opponent (Angelou & Economides, 2009). In mathematics, this can be represented as follows:

If we let:

X = the overall outcomes of competition;
Y = the overall outcomes of collaboration;

and strategy tends to either competition or collaboration, thus, if the game is zero-sum:

$X + Y = 1$

If the game is non-zero sum, then $X + Y = 1$ becomes a constraint which is relaxed. In this case, the general assumption is that total rewards can be increased. And so:

$X + Y > 1$

It has been argued above that this assumption is faulty, because resource depletion – coupled with increasing demand – mean that in actual fact, the maximum rewards possible will tend to decrease as the available mineral resources reduce. Thus, the actions of companies cannot bring about an increase in total rewards. When converted into mathematics, this means:

$X + Y < 1$

In a conventional understanding of Game theory, then the strategy which is best to be adopted by each opponent is competitive for a single game, and repetitive for an extended series (strictly

in an extended series, the best strategy is to use the one adopted by your competitor in the last round – which tends towards either all competitive or all collaborative):

For single game:
X >Y

But for series:
Y > X

In an environment of depleted resources and increasing scarcity – in which outcomes are reducing – it becomes necessary to question what happens as far as optimum strategies are concerned; this is the main question to be addressed in this thesis. This environment is different, and it must be expected that an ongoing reduction in total available outcome will exist and continue, as the world enters this new environment of resource shortages. In order to model this, it is important to start the analysis by describing this new environment.

For the economy as a whole, it is a situation that the number of games is effectively infinite, and therefore can be treated in this manner – as in the second extension mentioned above. The analysis to be undertaken applies similarly to the global economy and to a market for a particular type of good or service. There are a large number of participants and transactions, which make the analysis such that it can be treated as infinite. Thus, neither scale of analysis nor timescale will have any effect upon the mathematics or on the conclusions derived.

For the global economy, this can be modelled as follows:

Let n = number of rounds, $n \to \infty$;

And let I = world economy;

Therefore:

$$\sum_{n\to\infty}(X + Y) = I$$

4.4.1.4 The Gaia Game extension

Therefore, it becomes necessary for a new game[62] extension to be devised, which is a variation of the basic game, and it has been called the Gaia Game (in empathy with James Lovelock) as follows:

Game basics:
a, b = outcomes from competition
A, B = parties involved

		B	
		ab	b(1-a)
A		a(1-b)	(1-b)(1-a)

The outcome of any game is:

$$\sum [ab + b(1 - a) + a(1 - b) + (1\text{-}b)(1 - a)] \geq 1$$

However, for this extension, the outcome is reducing, so that:

$$\sum [ab + b(1 - a) + a(1 - b) + (1\text{-}b)(1 - a)] < 1$$

Which means:

$$\sum (\text{outcome from strategic decisions}) < 1$$

4.4.1.5 The Resources Paradox

As mentioned in section 3.12.4, there is a perpetual conflict for firms (and also governments) between the need to compete – in order to grow – and the need to collaborate – in order to make best use of remaining resources. This creates a continuing dichotomy in motivation and a need to reconcile these oppositional motivations, as shown below:

[62] In fact, it is merely an extension of the basic game, and so is called the Gaia Game extension.

$$\sum_{n,m} Y > \sum_{n,m} X$$

And

$$\sum_{n,m} Y < \sum_{n,m} X$$

Where:
m = number of firms;
n = number of rounds;
X= the effects of cooperation;
Y= the effects of competition.

This is discussed further in section 4.6.

Therefore, from these extensions, it becomes possible to build a model with which to explore the problem.

4.5 Building the model

By investigating the problem firstly at the global level, it can be seen that the pertinent problem for sustainability is to build the maximum output from the available mineral resources. And here, maximum must be taken to mean not in terms of economic value created, but rather in terms of maximum utility created – in other words, it becomes necessary to make best use (for the world as a whole) of what minerals are available, recognising both current needs and future needs. Any solution which fails to maximise utility would be based upon economic wealth or political power, and this would be unlikely to lead to a globally sustainable solution. A globally sustainable solution depends upon acceptability by all the people of the planet.

Thus, for the global economy, it is true that:

I = R + T

Where:

I = the world economy;
R = resources available;
T= transformational process.

It is possible to collectively describe business processes as consisting of a set of inputs on which operations are performed, in order to increase their value and transform them into outputs (Richards, 1960; Atrill & McLaney, 2018) including profit. Therefore, the purpose of every business can be considered to be adding value through these transformations made during its processing. This is known as the transformational process, which is shown as:

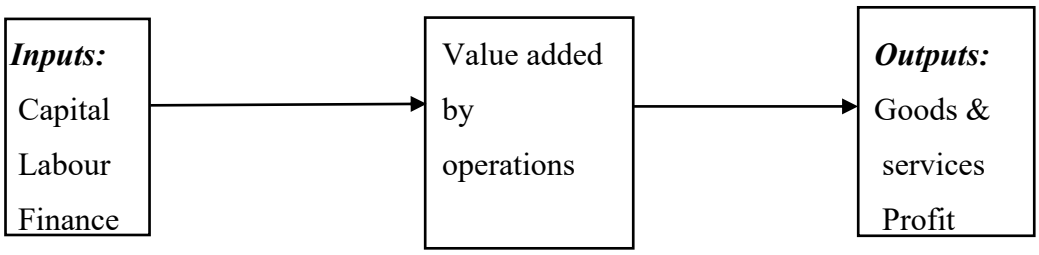

Figure 4.1 – The transformational process

In chapter 2 (section 2.9), it has been shown that there exists an almost unquestioned assumption that growth remains possible and desirable. In this thesis, it is argued that this analysis is incorrect as our understanding has increased (see section 2.12.1), and that sustainability is more complex than merely an economic problem, and consequently, cannot be resolved merely through the market. This contradiction between growth and sustainability has been recognised more recently by such writers as May (2008) and Zellner & Reeves (2012), who do not, however, seem to recognise the long-term problem in their reconciliation of the contradiction. This can be highlighted by a consideration of the transformational process.

In this process, it is assumed that the inputs (of capital, labour and finance) are used to make something by use of the operational factors of production (i.e. employees, suppliers, etc), in order to create goods and services with consequent profit. In this context, the term “capital” is used to mean all the factors of production from the environmental world, equating to capital assets and raw materials – and not just finance as normally assumed. There is an implicit assumption that these inputs can be freely acquired in the necessary quantities, and that the operational factors of production are commodified. It also assumes that one factor of

production can be readily substituted for another – at least to an extent – which is not the case. Mediation through the market is considered sufficient and is legitimated in views of such as Spangenberg (2004) referred to in section 2.9.

However, according to Crowther & Ortiz (2006) and Holsapple, Lee-Post & Pakath (2014), there are two basic problems with this analysis:

1. Capital, as an input, in reality represents environmental resources, and these resources are definitely fixed in quantity. In such a case, the market is not able to mediate adequately, as it will result in competitive bidding for what is available. This will raise the price (which is ok for a scarce product), but will also increase the transaction cost. However, it will not bring more of the resource into the market, because there is no more in existence. So in effect, it will result in a fight between competing companies. Substitution can compensate for shortages, only to a limited extent: it is difficult to envisage the possibility of labour compensating, for example, for the absence of oil. There is also the likelihood that the resource is acquired by the rich and powerful, and used for their benefit rather than the need of the world. For example, it would not be sustainable if copper was used to make jewellery for rich people rather than electrical wiring for less affluent countries. Thus, the market fails to optimise distribution for the benefit of the world.

2. It is not realistic to consider all the factors of production to be merely commodities, and thereby interchangeable: actually, some (e.g. labour) are stakeholders to the organisation. It is easy for analysis to consider them as commodities, but they actually require some benefit from the organisational use of them. When resources are accepted as finite, then mediation by the market does not satisfactorily meet the needs and expectations of all stakeholders. In reality, the effects on these stakeholders are a part of the output section of the transformational process.

The true transformational process is actually:

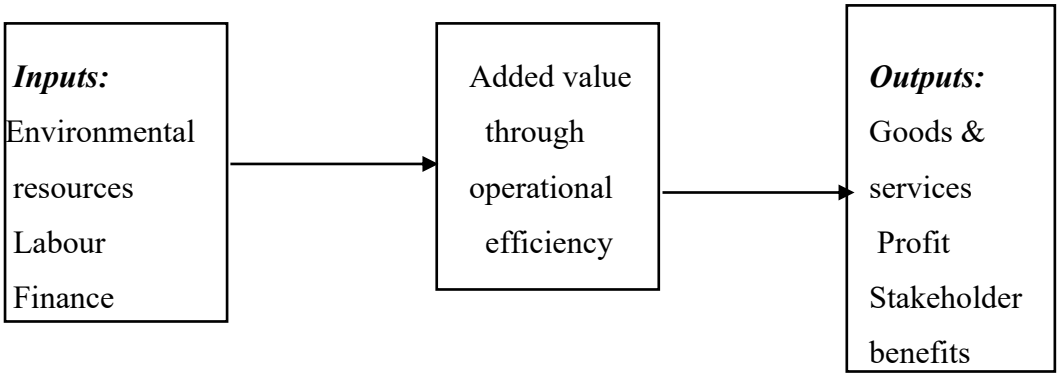

Figure 4.2 – Equitable Sustainability and the Transformational Process (Crowther 2008)

Of course, there are a number of such stakeholders who are concerned about the activities of the company, and are affected by those activities. The most significant of these are both the local community and society as a whole. These are additional to what are normally considered to be the major stakeholders such as investors and customers. In addition to an interest in the activities of the company, these other stakeholders have some influence over decisions about those activities. Indeed, David et al. (2010) state that this influence is sufficient that it equates to quasi-ownership of the organisation. From this, it can be asserted that sustainability can only exist, if equity also exists – and this equity must be such that benefits and effects are distributed, in a manner considered to be fair enough to satisfy all parties.

In reality, the world is approaching a situation in which, all resources are fully utilised, and those remaining are actually reducing and not increasing. In such a situation, increasing the total returns by development alone is impossible, as there are no extra resources available for this. This means that any development can only be achieved by different means – which effectively requires the use of any available resources in a more effective manner. Thus, the attempt to maximise returns in this new environment necessitates different behaviour. This means that in order to maximise "I" (the size of the world economy), this must be recognised:

$$I = \sum_{n,m}(X + Y)$$

Where:
I= the world economy;
m = number of firms;
n = number of rounds;
X= the effects of cooperation;

Y= the effects of competition.

In this new environment of raw material scarcity, the transformational function is different because both technological change and distributional effects assume increased significance. When resources are restricted, then technological change is one significant way to produce more from the same amount of resources. Technological development determines the rate at which this happens (see Atkinson & Stiglitz, 1969). It has been shown that all stakeholders are affected by the activities of the firm, with some effects being positive and some negative. For example, from the same activity, it is possible that employees receive payment, whereas local community suffers from traffic congestion and pollution – even though the local community also includes some employees. Equity becomes important as it ensures that the distributional effects leave everyone as reasonably content – known as satisficing (Simon, 1956).

In other words, the transformational process can be achieved by:

$T = t + d$

Where:

T= transformational process;

t=technological change;

d=distributional effects.

Consequently, the global economy can be described differently:

$I = R + T$

$= R + (t + d)$

where:

I = the world economy;

R = resources available;

T= transformational process.

For sustainability and development, the aim is to maximise I, in a situation in which R is decreasing as resources become depleted. In fact, the world economy will only grow if the rate

of change of the transformational process exceeds the rate of change in available world resources, thus:

$\delta T > \delta R$.

As R is decreasing in value, then T must be maximised, and therefore t + d must be increased so that:

$\delta(t + d) > \delta R$

As these imperatives are accepted and progress towards them is achieved, then there will inevitably be some changes to the economic system. However, at the moment, it seems that most politicians and economists simply assume that the world economy (I) will automatically increase due to the market system in operation (e.g. Fischer, 1993; Hondroyiannis et al., 2005; Bazzi & Clemens, 2013).

4.6 The model in operation

It seems clear that the present environment is one in which resources are decreasing through depletion, and consequently, future development will only happen if strategic decisions are made and implemented accordingly. Indeed, strategy and planning become even more important to ensure remaining at the same level of activity, let alone development – the real definition of sustainability. For this, the two aspects already identified – namely technological development and distributional effects – are essential in combination. According to Romer (1990), the rate of technological change has remained fairly constant over recent decades; this finding is confirmed by The Emerging Future (2012). Therefore, this requires the focus to change to distributional effects and the need to plan and monitor these. This means that the distribution of effects and benefits must change. This would require external intervention which can be described as governance or regulation – in other words, outside control by some means. It is described here as the Gaia extension.

Currently, the environment is changing and one effect is that mineral resources are becoming depleted; one consequence is that the total resources remaining are reducing due to their extraction and use. As a consequence, the optimum use of these shrinking resources is

necessary. Thus, the current game is not either zero-sum or increasing – and therefore some new mathematics is required. Additionally, a resolution to the resources' paradox is necessary. From satisfying these new conditions, it is intended to show what way should be adopted to get the best outcome for the world in this new environment.

The data shown earlier indicates that available resources are finite in supply and therefore in constant decline. This implies adoption of efficient production process which utilises fewer inputs to produce the same level of outputs. In effect, this would require optimizing the use made of the remaining minerals, and the alternative ways of achieving this are to either leave it to the market and let the interactions between supply and demand decide the optimum use, or to have some form of global intervention such as regulation, which is depicted below as figure 4.3. These two alternatives are labelled as competition and cooperation, and the question addressed is which of these leads to the better outcome in terms of long-term global sustainability.

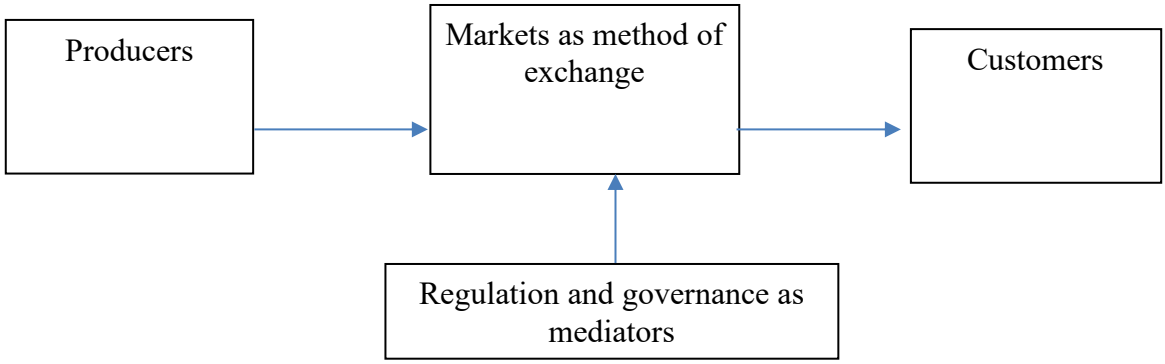

Figure 4.3 – Strategic Model Suitable for Current Environment

These two strategies, i.e. cooperation or competition, are applied to the current environment. Of course, the costs of extracting and processing minerals will change according to technological development and ability to access those resources, but will remain unchanged whatever the method of distribution adopted. Therefore, these costs can be discounted from the analysis, which needs to focus upon what will change between the alternatives.

In case of adopting the strategy of competition, this would mean leaving the distribution of minerals available to market forces. The increasing scarcity in mineral supply will inevitably bid the price up. This will encourage greater recycling and greater technological developments

– either in its use or in the use of substitutes. Additionally, as the mineral becomes scarcer, firms requiring it for their production will need to compete more with each other in sourcing supplies and purchasing them to be transported to where they are needed for production. This will in effect increase the transaction costs involved in the acquisition of the mineral.

Adopting the cooperation strategy would require distribution of the available mineral supply to be in accordance to an agreed method which would be determined globally. Such a method would distribute according to utility derived rather than price, and allocating in this way is termed governance. Thus, instead of transaction costs being affected, the governance mechanism would impose its own costs. It may be difficult to derive such a method of distribution and organising a global system, but it may well result in a better long-term solution which would be more sustainable, rather than being dependent upon extant wealth as market forces would assume. Therefore, the question arises as to which mechanism is better for the world, and hence, both for the individual firms and countries in possession of available minerals and for firms and countries in need of these for production. This is the central question of the thesis, and can be seen to be significant for global sustainability. The model produced addresses this question, and in doing so, it assumes that such factors as technological development (both in extraction effectiveness and in subsequent use in production), the development and use of substitutes, and the imperative to recycle are unaffected by the choice of distribution method. There is no evidence which suggests the imperative for any development in these would be caused by change in distribution methods, rather than by changes in supply and demand. Thus, such factors can be eliminated from the model built, as they will not affect the decisions made.

Actually, the resources' paradox is basically about considering the conflict between long-run advantages and short-run necessities. It is similar to the discussions of Laverty (2004) about the value placed upon the long-term in decision-making. In fact, as Saez & Requina (2007) argue, sustainability requires investment; this means that in order to achieve sustainable advantages in the long-run, present benefits would be reduced, which is equal to investing for future. However, countries and firms are only willing to invest for the future when – through a sort of net present value calculation – they realise that costs of such investment are less than their benefits; conversely, Chichilnisky (1996) argues that changing the discounting factor changes the effect, and focusing upon sustainable factors rather than financial factors changes the discounting undertaken. This dichotomy has been investigated by a balance of evidence to

show that no conflict exists, and that actually the dialectic created is false (Crowther, 2012). However, the dichotomy has not been resolved through any mathematical testing, although one of the interesting aspects of the Prisoners' Dilemma is that the optimum course of action is never selected without external intervention (Amadae, 2016). Therefore, below is the mathematical justification.

4.7 Mathematical justification

The assumption is that in a simple game, there are two strategies, which are either cooperation or competition. If the game has only one round, then it is correct. However, if there are several rounds, then according to the last play, there are four strategies as below:

Compete, in case of competition from the other party;
Cooperate, in case of competition from the other party;
Compete, in case of cooperation from the other party;
Cooperate, in case of cooperation from the other party.

Each time the game is repeated, the same four strategies sustain. It can be depicted as a decision tree as below:

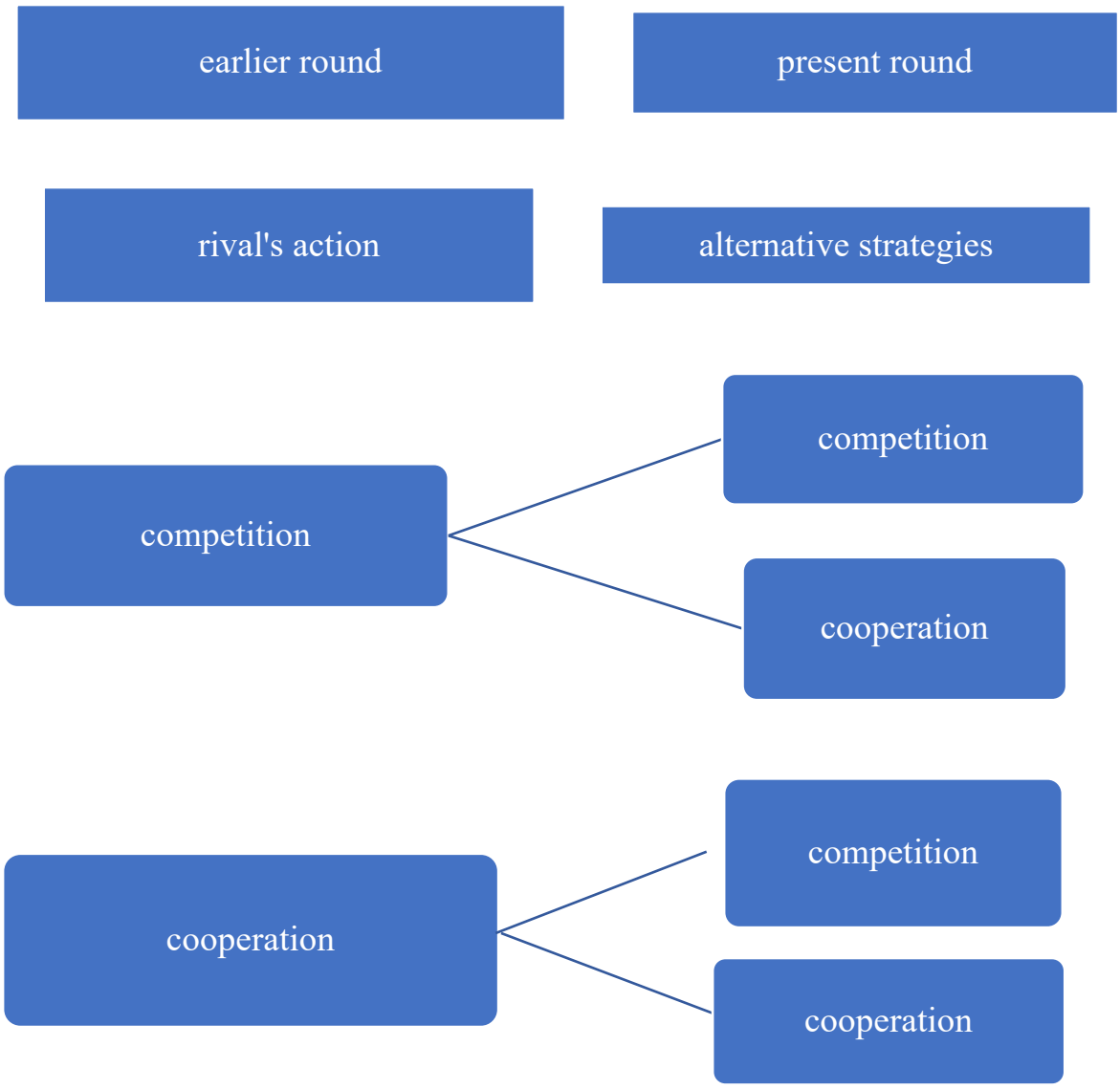

Figure 4.4 – Decision tree for the alternative strategies

It is important to recognise that supply is restricted and cannot be increased except at the expense of future availability. Whichever strategy is taken will have an effect on the further rounds of the game. So, in case the players (who would normally be the companies involved) both choose competition, as a result, the transaction costs will increase and the price of resources will bid up. In case both players choose collaboration, then there will be no additional transaction costs, but perhaps there may be a reduction in such costs, which will offset the increase in regulatory costs associated with the new governance arrangements.

At this point, it is stressed that what is of concern in this thesis is global sustainability and what matters is the outcome which best enables such sustainability. In terms of the game being designed, then the players are competitors in the scenario being evaluated. Normally, this would be the competing mineral extraction companies, but the game would operate just as effectively if the players were various governments competing against each other, or if the players were mineral processing companies competing against each other to obtain the necessary mineral resources. It is recognised that any individual player might gain an advantage in the short-term through their actions; this would not affect global sustainability but only the net benefit / loss of individual players. The finite supply of the mineral needs to be distributed equitably in order for sustainability to be achieved, and it does not really matter if that distribution is via one channel or another. In other words, there can be no winners in the game, except the world as a whole.

In order to model this as a game, a hypothetical set of data has been constructed and effects calculated. After this, sensitivity analysis has been undertaken to explore the realism of the model and underlying assumptions.

Based upon this hypothetical situation, it has been deemed adequate to initiate with this situation:

Ten percent of market share belongs to player “A”.
Rest of the market share belongs to all other players, collectively termed as “B”.
Here, it is assumed that market size is equivalent to a thousand units.

As explained above, the focus of the game has to be upon the global market for distribution of the mineral resource, as sustainability depends upon how this is distributed. Therefore, it follows that the players are the players in the market: these are primarily firms or governments, according to how the mineral materials are distributed. In either case, there are only a small number of players, and essentially there are only two alternative courses of action. Therefore, it is reasonable to treat the players as just two players, while recognising that each “player” probably consists of several firms or governments, and that these can change from one player to the other for each round. The analysis will not change at the strategic level considered by treating the players as two or more, regardless of whom each player consists of, as the outcome of concern is to decide which method of distribution better fosters global sustainability. Thus,

what is being concerned is benefit to the world, and from this perspective, the effects upon individual players is not relevant; only the method of distribution is of concern.

Therefore, the game starts like this:

		B	
A		Competition	Cooperation
	Competition	100, 900	100, 900
	Cooperation	100, 900	100, 900
	Total size of market: 1000		

All players will follow one of the two strategies, as a mix of the two cannot really be pursued. Therefore, the market can be modelled as two players – A & B. It should be noted that in considering player A for our analysis, it is acknowledged that some of the other players may also select the same – rather than the alternative – strategy. This will not change the nature of the game as a two-player game, and will only change the relative balance between the two sets of players. The analysis will remain unchanged.

Therefore, the following subsequent assumptions can be made:

1. As discussed before, the amount of remaining resources is decreasing. Here, we assume that there is a perfect correlation between production potential and decrease of resources. Therefore, an assumption is made that in every round of game, remaining resources would shrink by one percent.

2. As already contended, transaction costs will increase when competing, and as a result, there will be a diversion of resources to competing and marketing, instead of producing. Therefore, it can reasonably be supposed that if each individual chooses competition, the market size for subsequent round will only reduce by one percent. In case, only one player chooses competition, then the rise in its market share for the following round can be assumed to be five percent.

3. As a result of cooperation, resources would be used optimally, which is equal to gaining more output out of such resources. Thus, the assumption can be that when each firm chooses collaboration, then in the following round of game, the market size will only decrease by one percent, as no matter what the players might do, the resources will, however, decrease. Moreover, it can be contended that the efficiency gains because of collaboration are actually equivalent to the competition costs. That is to say, these gains can be considered as the amount not lost by competition, which can mathematically be written as x=e.

4. The actions taken will just affect the following round.

NB: The values have been chosen for illustration purposes and do not attempt to portray actual figures. Actual figures will be used in testing the model after it has been fully developed.

Therefore, the following round would seem as follows:

Basic game

a, b = outcomes from competition
A, B = parties involved

	B	
A	a.b	a.(1-b)
	(1-a).b	(1-a).(1-b)

And

$$\sum[a.b + (1-a).(1-b) + a.(1-b) + (1-a).b] < 1$$

Hence, from the perspective of A:

		B	
A		Competition	Cooperation
	Competition	98,882	54, 936
	Cooperation	104, 886	99, 891
	Total size of market: 980,990		

Here are the estimations:

A		B	
		Competition	**Cooperation**
	Competition	**98, 882**	**104, 886**
		Resources shrinkage and competing will each cause one percent reduction in the total market. It is applicable to all players.	Resources shrinkage will lead to one percent reduction in total market. Player B is not in competition, which leads to five percent benefit for player A.
		54, 936	**99,891**
	Cooperation	Resources shrinkage will cause one percent reduction in the total market. Player A is not in competition, which leads to five percent benefit for player B.	Just shrinkage of resources

Clearly, if one player chooses cooperation (which is player A in this case) and the other player chooses competition, then the result will be detrimental for player A. Hence, such a strategy cannot be considered as sustainable, and competition should expect retaliation. Therefore, whenever one of the players competes and the other one cooperates, the next expected strategy will be competition for both: so, the only surviving combination of strategies are either to cooperate for both or to compete for both. It is in line with the previously made remark that the strategies will tend towards the extremes of either strong competition or strong cooperation (Luce & Raiffa, 1957). Therefore, it is possible to show the viable strategies as:

	B		
A		Competition	Cooperation
	Competition	98,882	
	Cooperation		99,891
Total size of market: 980, 990			

It is completely noticeable that for all the players, cooperation is the more powerful strategy. However, one should realise that the existing economic model is completely based on competition, which is the common practice.

Hence, tracking these strategies in ten rounds would be suitable here:

First Round

	B		
A		Competition	Cooperation
	Competition	98,882	
	Cooperation		99,891
Total size of market: 980, 990			

Total size of market reduces by one percent in every round due to resources reduction, and either: another one percent due to competition, or no reduction due to cooperation. Therefore, when both players cooperate, the only change will be one percent related to decreased resources, but when they both compete, the reduced amount will be two percent. Hence:

Second Round

	B		
A		Competition	Cooperation
	Competition	96,864	
	Cooperation		98,882
Total size of market: 960, 980			

Third Round

	B		
A		Competition	Cooperation
	Competition	94,847	
	Cooperation		97,873
Total size of market: 941, 970			

Fourth Round

	B		
A		Competition	Cooperation
	Competition	92,830	
	Cooperation		96,864
Total size of market: 922, 960			

Fifth Round

	B		
A		Competition	Cooperation
	Competition	90,814	
	Cooperation		95,864
Total size of market: 904, 960			

Sixth Round

	B		
A		Competition	Cooperation
	Competition	89, 797	
	Cooperation		94,856
Total size of market: 886, 950			

Seventh Round

	B		
A		Competition	Cooperation
	Competition	87, 781	
	Cooperation		93,846
Total size of market: 868, 939			

Eighth Round

	B		
A		Competition	Cooperation
	Competition	85, 766	
	Cooperation		92,838
Total size of market: 851, 930			

Ninth Round

	B		
A		Competition	Cooperation
	Competition	83, 751	
	Cooperation		91,829
Total size of market: 834, 920			

Tenth Round

	B		
A		Competition	Cooperation
	Competition	82, 735	
	Cooperation		90,820
Total size of market: 817, 911			

It can be seen that as each round proceeds, the available market shrinks, and the comparative difference between the collaboration and competition approaches becomes larger. However, these are, just an illustration, and an actual model is needed to determine the outcomes.

Thus, the above rounds could be modelled into two different outcomes like this:

Outcome from competition= $\sum_{n,m}(1-x)(1-s)I$

Outcome from cooperation = $\sum_{n,m}(1+e)(1-s)I$

Where:
"e" is efficiency gains regarding utilization of resources through cooperation – i.e. the effects of not increasing transaction costs – and the value of "e" ranges from $0 \ll e \ll 1$.
"I" is the world economy;
"m" is overall number of players operating in the market;
"n" is the number of rounds. Because the number of rounds keeps on repeating infinitely, so it can be written as $n \to \infty$.
"x" is the costs related to competition, and the value of "x" ranges from $0 \ll x \ll 1$.
"s" is the size of remaining resources which is changing, and its value ranges from $0 \ll s \ll 1$.

From the evidence so far, it is apparent that cooperating is preferable – i.e. less costly than competing – and hence, it can be explained mathematically as follows.

$\sum_{n,m}(1+e)(1-s)I > \sum_{n,m}(1-x)(1-s)I$

This means that total market size due to cooperation is greater than total market size due to competition.

4.7.1 Sensitivity analysis

This technique is aimed at specifying a decision's outcome, when a main predicted value appears to be untrue. Therefore, it can be stated that sensitivity analysis is about understanding the way to divide the quantity or quality of changes in a mathematical model's outcome into separate causes of changes in the same model's input (Saltelli, 2002). Or, it can be stated that sensitivity analysis is the method to assess the extent of variation required in the assumptions to make any change in the outcome (Saltelli et al., 2004; Roddam, 2005).

The analysis carried out above needs assessing in terms of its sensitivity to any assumptions leading to inaccurate analysis. The inequality above can only be true if the following holds true:

$$(1 + e) > (1 - x)$$

Or, it can be expressed that the following statement should always be true.

$$\delta(1 + e) > \delta(1 - x)$$

This can be interpreted that the variations due to efficiency gains in use of resources as a result of cooperation should be more than the variations in costs of transaction and resources price due to competition. It can be observed that this should be correct, because variations due to competition always lead to increased costs of transaction related to bidding for scarce raw materials, which will lead to increased price for resources. Equally, of course, competition would not reduce such prices. In the same way, gains achieved by efficient use of resources, as a result of cooperation, always leads to a reduced pace in resource depletion and cannot add to this pace. If it is considered that these do not affect the situation, then the above statement would change to equality, as follows:

$$\delta(1 + e) = \delta(1 - x).$$

Of course, this would only make the assumptions not relevant, but still valid.

Therefore, the model is shown not to be sensitive to variations in assumptions. So, cooperation is shown to be always a better strategy than competition. Although single players might achieve short-run gains through competition but these achievements are not long-lasting; moreover, such gains adversely affect the whole society, because resources are diverted into competition. Besides, the long-run result would be that other players also retaliate, so it seems that the player will only be benefitted for a short period. It brings us back to the resources' paradox, which states that there is a simultaneous tendency for the players to both cooperate and compete.

Obviously, this paradox does not exist for the society, because it is always better for the society to cooperate. The same is about every single customer, who will also be benefitted likewise. It can be claimed that competition inspires development and invention (Maris & Mueller, 1980), which is one of the claimed benefits of the competitive economic market system which currently operates. However, there is no evidence that a collaborative approach would lessen development, and it can be argued that collaboration – and the probable consequent sharing of resources and expertise – will actually promote development. Sadly, the system has never been attempted to show this to be true. Therefore, it is needed to understand what is possibly required to guarantee cooperation, as according to Buchanan (1975) and Hobbes (1651), this will never happen, and therefore, will never be the outcome in the "Prisoners' Dilemma". Single companies always wish to compete and gain benefits in short-run, unless there exists relevant requirements about it. Such kind of practice is a part of economic culture, where companies tend to compete as the ubiquitous strategy in the market.

The argument for companies existing is that people can achieve their greatest interest by cooperating through organisations, rather than every person acting individually. According to the above argument, Coase (1937) established the theory of the firm, which discusses that such a gathering of people together reduces the individual transaction costs, which will therefore lead to a higher efficiency. However, it is only true if the resources that companies are bidding for are effectively infinite and the market is unrestricted. If resources are in very short supply, then companies would need to compete with each other to gain the limited resources, which leads to higher costs of transaction. For global sustainability, therefore, it is apparent that some form of regulation is needed.

4.8 Operation of regulation as a mediating factor

As already discussed, the impact of regulation and the way it can alter the model just provided should be assessed. It was discussed earlier that competition raises the costs of transaction but without any incentives, it is unlikely that cooperation would happen. Regulation creates such incentive, although cost of market activity will also raise through regulation.

Therefore, it has been decided now to model it by repeating the same scenario as follows.

Company "A" owns ten percent of the market,

The whole other companies in the market are shown by “B”,
The total market size is assumed to be a thousand units.
Therefore, the initial game seems like this:

	B		
A		Competition	Cooperation
	Competition	100,900	100,900
	Cooperation	100,900	100,900
Total size of market**: 1000**			

The set of four assumptions that were previously made for the previous modelling will remain unchanged. In order to include the impact of regulation here, it is required to add a new assumption.

5. The aim of regulation is – as a minimum – to encourage cooperation, and if needed, even to force it so that the whole society and the world market be benefitted from it. Therefore, the two strategies of either to cooperate or to compete are repeated here. As a result of regulation, resources will be focused on control and monitoring – instead of producing – therefore, the transaction cost will rise. Here, an amount of 0.2% is assumed for this. Obviously, there is a cost for regulation. However, this cost is generally a small amount. As an instance, the suggested tax that Tobin considered is 0.5% (Tobin, 1978; 2001). In the following section (section 4.9), the amount of 0.01% is calculated for the regulation cost for the USA. It seems that no-one has actually estimated the cost of regulation of the market, and so, these are the best estimates available. On this basis, therefore, it is argued that it is quite reasonable to apply an amount of 0.2%.

So, the subsequent round can be described as follows:

Basic game

a, b = outcomes from competition

A, B = parties involved

	B	
A	a.b	a.(1-b)
	(1-a).b	(1-a).(1-b)

And

$$\sum[a.b + (1-a).(1-b) + a.(1-b) + (1-a).b] < 1$$

However, the only options that are of concern are either for both to cooperate or for both to choose competition.

Hence, from the perspective of A:

		B	
A		Competition	Cooperation
	Competition	98,882	
	Cooperation		99, 889
	Total size of market: 980,988		

Here are the estimations:

		B	
		Competition	**Cooperation**
A	**Competition**	**98, 882**	
		Resources shrinkage and competing will each cause 1% and regulation will cause 0.2% reduction in the total market. It is applicable to all players.	
			99,889
	Cooperation		Regulation and reduced resources will, in turn, cause 0.2% and 1% reduction in the total market.

It is completely noticeable that for all the players, cooperation is the more powerful strategy. However, one should realise that the existing economic model is completely based on competing, which is the common practice. Therefore, some force is normally needed to enforce compliance.

Hence, tracking these strategies in ten rounds would be suitable here as well:

First Round

	B		
A		Competition	Cooperation
	Competition	98,882	
	Cooperation		99,889
Total size of market: 980, 988			

Total size of market reduces by one percent in every round – due to resources reduction – and another one percent – due to competition – but it does not reduce with a strategy of cooperation. Besides, the cost of regulation is 0.2%. Therefore, when both players cooperate, the change will be 1.2%, but when they both compete, the reduced amount will be 2.2%. Hence:

Second Round

	B		
A		Competition	Cooperation
	Competition	96,863	
	Cooperation		98,878
Overall Market Size = 959,976			

Third Round

	B		
A		Competition	Cooperation
	Competition	94,844	
	Cooperation		97,867
Overall Market Size = 938,964			

Fourth Round

	B		
A		Competition	Cooperation
	Competition	92,825	
	Cooperation		96,857
Overall Market Size = 917,953			

Fifth Round

	B		
A		Competition	Cooperation
	Competition	90,807	
	Cooperation		95,847
Overall Market Size = 897,942			

Sixth Round

	B		
A		Competition	Cooperation
	Competition	88,789	
	Cooperation		94,837
Overall Market Size = 877,931			

Seventh Round

	B		
A		Competition	Cooperation
	Competition	86,772	
	Cooperation		93,827
Overall Market Size = 858,920			

Eighth Round

	B		
A		Competition	Cooperation
	Competition	84,755	
	Cooperation		92,817
Overall Market Size = 839,909			

Ninth Round

	B		
A		Competition	Cooperation
	Competition	82,738	
	Cooperation		91,807
Overall Market Size = 820,898			

Tenth Round

	B		
A		Competition	Cooperation
	Competition	80,722	
	Cooperation		90,797
Overall Market Size = 802,887			

The above rounds could be modelled into two different outcomes like this:

Outcome from competition = $\sum_{n,m}(1-x)(1-s)I$

Outcome from cooperation = $\sum_{n,m}(1+e)(1-r)(1-s)I$

Where:

"e" is efficiency gains regarding utilization of resources through cooperation and the value of "e" ranges from $0 \ll e \ll 1$;
"I" is the world economy;
"m" is overall number of companies operating in the market;
"n" is the number of rounds. Because the number of rounds keeps on repeating infinitely, so it can be written as $n \to \infty$;
"r" is the regulation costs and its value ranges from $0 \ll r \ll 1$;
"x" is the costs related to competition and the value of "x" ranges from $0 \ll x \ll 1$;
"s" is the size of remaining resources which is changing and its value ranges from $0 \ll s \ll 1$.

From the evidence so far, it is apparent that cooperation is preferable, i.e. less costly than competition, and hence, it can be explained mathematically as follows:

$\sum_{n,m}(1+e)(1-s)(1-r)I > \sum_{n,m}(1-x)(1-s)I$

This means that total market size due to cooperation is greater than total market size due to competition.

It is equal to the following inequality:

$$\sum_{n,m}(1+e)(1-r) > \sum_{n,m}(1-x)$$

Therefore, it can be suggested that if the following inequality exists, then it is always better to cooperate than to compete:

$$x > r + er - e$$

Which means the following inequality should always hold.

$$\delta x > \delta(r + er - e)$$

It is possible to test this inequality, but the data adequate for doing so is not available. In order to perform the testing, then approximated measures will need to be used. These are obtained by interpolation from reported data, as explained in each instance in chapter 5. Currently, no data exists that would be used as the competition cost, either in company level or at worldwide level. In chapter 5, this will be dealt with in detail, where the analysis will be performed on actual data. The model is applied to different real data in a variety of settings, as described in chapter 3.

Problems about access to proper data or even to proper surrogate data necessitates initially to examine if any more proof can be provided mathematically. This is what is done next by doing linear programming.

4.9 Performing Linear Programming

Linear programming refers to a quantitative approach to determine the optimal utilization of resources; in this regard, it is helpful to managers.

For this technique to be suitable for optimal allocation of resources, some requirements as follows should be observed:

- There should be a specific objective for the market that it desires to fulfil. Linear programming is usually applied for a company, but here it is applied to the existing global market (i.e. the whole market), while market is simply the expression used; this in fact means a worldwide consensus on the utilization of raw materials as moderated by a kind of regulation. As an instance, for a company, it might be minimisation of costs or maximisation of investment's rate of return or profits. However, in this case, the desire is maximisation of available resources for production. So, it can be taken as the objective of the study.

- Market should have different options available in order to accomplish its objectives. In case there are no options available, therefore, there is no need to make any decision and there is no problem about allocation of resources. As discussed before, in this case, competition is the option available instead of cooperation through regulation.

- Another prerequisite is the limitation of available resources, therefore the problem to be addressed is the maximised utility of the limited resources. Here, this is precisely the question with the objective of minimisation of their reduction rate.

- Market's objective and its limitations for utilization of resources should be citable in mathematical form, either by equations or inequalities.

All these prerequisites are already observed, therefore, it is possible to express the problem in this way. Usually at the start, the feasible range is specified for the linear programming case. However, the problem in this study is a bit different. In this case – based on the decision taken – the feasible range reduces in various rates; the reason for this reduction is that the available resources shrink. It reduces at various rates, based on the amount of resources spent for competing or regulating. Therefore, the feasible range is non-static, and in fact, an area exists which includes this range and its variations in time. In effect, this is linear programming looked at over time rather than as a static problem. Actually, there is one feasible area for cooperation and one for competition and the optimum is found by comparing these two areas together.

The feasible area for cooperation is shown by the following constraints:

$F_{co} = z(1 - r)(1 + e)$

Where:

F_{co} is the cooperation function;

"z" is the change in total capacity of production; which is I(1-s)

"e" is efficiency gains regarding utilization of resources through cooperation and the value of "e" ranges from $0 \ll e \ll 1$;

"I" is the world economy;

"r" is the regulation costs and its value ranges from $0 \ll r \ll 1$;

And,

$F_{co} = z$.

The latter constraint is achieved when there is no change from the existing condition, i.e.,

r = 0 & e=0

This is represented in the following graph:

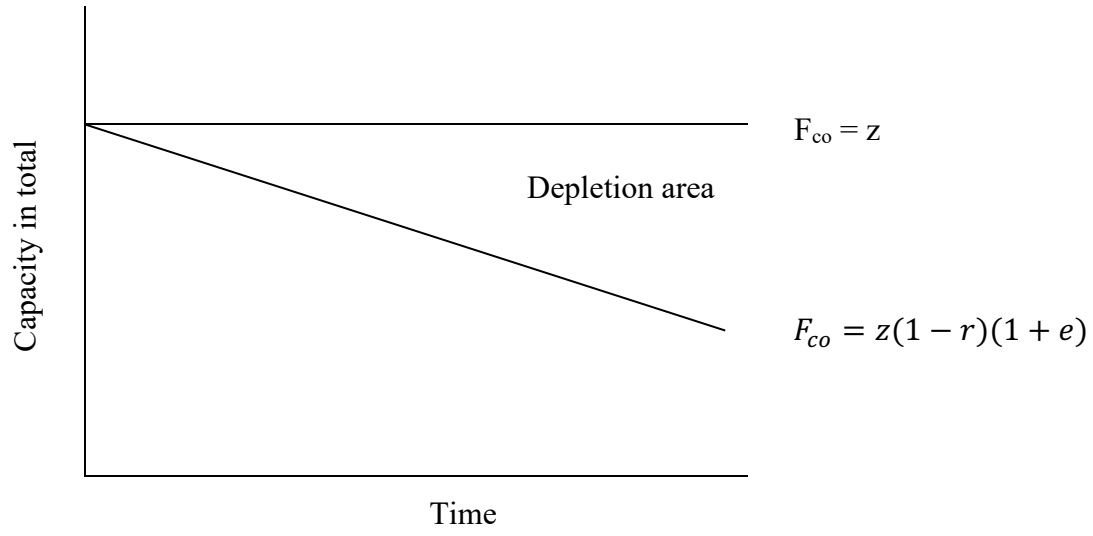

Fig 4.5 – Rate of depletion in the case of cooperation

it can be seen that the amount of available resources is decreasing over time, due to extraction and use of the mineral. Therefore, in order to determine the area, it is assumed that the time period ranges from zero to infinity, which is in line with the described extensions to the approach by the economists. Hence, it is possible to calculate the depletion area in this way:

$$Depletion\ Area = \int_{z=0}^{z=\propto} zdz - \sum_{z=0}^{z=\propto} z(1-r)(1+z)dz$$

This equation is resolved as

$$(rz^2 + rez^2 - ez^2)/2 \ where\ z = 0\ to\ \propto$$

The same method is used for competing but the equation used for the competition function is as follows:

$$F_{cm} = z(1-x)$$

Where

F_{cm} is the competition function;
"z" is the change in total capacity of production; which is *I*(1-s);
"x" is the costs related to competition and the value of "x" ranges from $0 \ll x \ll 1$
"I" is the world economy.

However, as before, the two extremes in the equation define the area of depletion.

One of the extremes is where there is no change from the existing condition, therefore

x = 0

hence, one of the extremes can be shown like this:

$F_{cm} = z$

This is represented in the following graph:

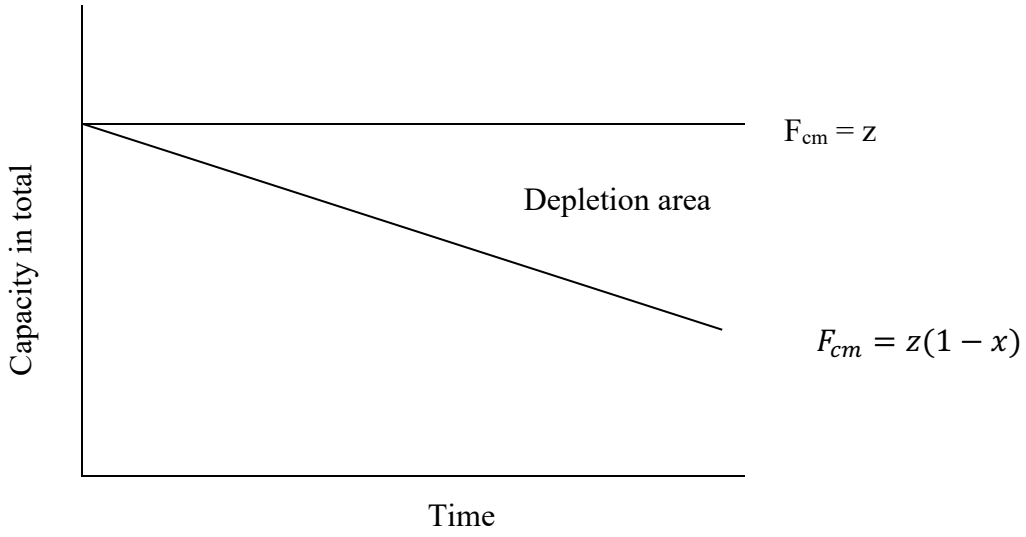

Fig 4.6 – Rate of depletion in the case of competition

Therefore, in order to determine the area, it is assumed that the time period ranges from zero to infinity, which is in line with the described extensions to the approach by the economists. Hence, it is possible to calculate the depletion area in this way:

$$Depletion\ Area = \int_{z=0}^{z=\propto} zdz - \sum_{z=0}^{z=\propto} z(1-x)dz$$

This equation is resolved as:

$$xz^2/2\ \ where\ z = 0\ to\ \propto$$

Now, in order to determine the more effective strategy, the two calculated areas should be compared and decide which one is bigger. It can be determined by subtracting one area from the other one, as follows:

$$(rz^2 + rez^2 - ez^2)/2 - xz^2/2$$

The better strategy is the one with the smaller area. Therefore, if the result of the equation is a positive amount, then the more productive strategy will be to compete. So, this is what we need to show:

$(rz^2 + rez^2 - ez^2)/2 - xz^2/2 < 0$

Therefore, the highest values should be considered for the involved variables. Here are the variables:

"e" is the efficiency gains in use of resources due to cooperation;
"r" is the regulation costs;
"z" is the change in total capacity of production;
"x" is the competition costs.

It was already argued that efficiency gains are actually the complement of the competition costs. Or, one can say that the efficiency gains are the losses that are not going to occur by competition. Therefore, it is reasonable to claim as follows:

e = x

so, it is possible to write the above inequality like this:

$(rz^2 + rez^2 - 2ez^2)/2 < 0$

Now, it is required to find out the values that prove the inequality to hold or not to hold. However, first it is needed to realise the values which are reasonable. It can first start by realising the regulation cost. Regulation costs are always kept very low, because if not, then they will affect negatively on trade. Usually, the costs of regulation are below one percent. For instance, Tobin (1978) suggested an amount of 0.5% as tax related to financial transactions. The Washington Post[63] in 2012 claimed an amount of $1.75 billion for the regulation costs of the government in the United States, which it considered as an excessively high amount (different sources have disputed this value. However, the smaller this value, the better this argument is reinforced). Therefore, considering that the country has a GDP of 15 trillion dollars, the regulation cost is equal to only 0.01%.

[63] http://www.washingtontimes.com/news/2012/jul/25/regulations-are-choking-small-business-engine-of-g/ accessed 13/5/2016

If 0.01% is assumed reasonable, then it can be substituted in the inequality to evaluate "e", which transforms the inequality into equation. Hence:

$(rz^2 + rez^2 - 2ez^2)/2 < 0$

When substituting r = 0.01%:

$(0.0001z^2 + 0.0001ez^2 - 2ez^2)/2 = 0$

In the above equation, it is possible to treat z^2 as a constant, and thus, remove it. (it is accepted that it is not actually a constant value, but the calculation is not affected by the value given to it, and therefore, it can be treated as a constant and eliminated from the calculation). Therefore:

1- 2000e + e = 0

And the value of e is calculated:

e = 0.00005

or it can be said that the gains gathered through cooperation or the impact of competition have to be below 0.005% so that the effects of competition would outweigh the gains through cooperation. As this value is very small, so it is not discernible, and it is possible to state that, if the assumption made in this section is valid, then in all possible situations, it is beneficial for the whole world to cooperate instead of compete. This assumption was that the global resources are finite – therefore, extra in one time period can only be obtained by a reduction in availability in a future time period; thus, it is only possible to gain more from other companies.

4.10 Conclusions from the calculations

The calculations undertaken in this chapter show mathematically that, in an era of resource depletion and reduction in the availability of mineral resources, it is better for society at large and consumers, and therefore, for the world, if the economic model of distribution of those resources is based upon collaboration rather than the current model of market competition. Moreover, the basic Game theory model of the Prisoners' Dilemma also demonstrates that an individual firm can only gain advantage from competition in the short-term – but in reality, the

economic model is a continuing series of games, and so, collaboration gives the best benefit to the world. This has been shown through a model which is tested by sensitivity analysis and calculated using both Game theory and Linear Programming. It seems to be that the calculations yield the same result in every scenario.

4.11 Chapter summary

Having shown in Chapters 2 and 3 that Game theory is a suitable technique to model the effects of resource depletion, this chapter has performed the required developments to Game theory and the mathematical calculations necessary to work out the effects. This shows that at the level of theoretical and mathematical calculus, the model is sound. However, to be certain, the model also needs to be tested with real data, and this will be the subject of the next chapter. In doing this, the model developed in this chapter will be applied to the scenarios described in chapter 3.

Chapter 5

Empirical testing and evaluation

5.1 Introduction

The previous chapter has developed the necessary modelling and extensions to Game theory and has shown their robustness at a theoretical level, and supported this by demonstrating that the same effects occur when using linear programming. These, of course, need to be further tested by applying them to actual data, and this is the purpose of this chapter. Previously, it was explained, in Chapter 3, that this would be done by using GDP data and data from industries and individual firms. The purpose of this chapter is to apply this data into the model and calculate if the effects still hold.

5.2 The Utilitarian Free Market

The free market has already been identified as the basis for the modern economic system of the world, which is argued to maximise economic wealth and optimise its distribution. This belief has been accepted universally – almost without question – and so, the world governments have been under more and more pressure to omit or lessen regulation, in order to provide the opportunity for all of us to enjoy the benefits of free market economy. Although the benefits of the free market have been discussed extensively (e.g. Berggren, 2003), omitted from the discussion was that this is the basis of Utilitarianism. The philosophy of Utilitarianism, of course, is based on the premise that total good outweighs total bad, howsoever it is distributed. The most extreme version of this has been vividly described by le Guin (1973) in her novella, where the happiness of the majority depends upon abject misery of one person. This raises a question of ethics, and ethics is totally missing from the free market approach to economic activity.

Transaction cost theory assists in acquiring knowledge about the process of transformation. This theory starts by claiming that every action taken in the firm is a transaction. It does not matter if such action is taken inside or outside the firm through interacting with outside environment. Therefore, these activities are all considered as transactions, no matter if they are carried out inside or outside the firm. There is a difference, however, in that the market

mechanism considers a price for transactions done outside the firm, whereas the lack of a market mechanism inside the firm leads to creation of accounting systems for activities performed inside the firm, which will make up for the lack of price as a market mechanism.

Every transaction has a cost related to it, apart from the exchange price. This cost is for involving in that transaction, for instance, the cost for a contract between agents and principals or the cost for providing raw materials. Theoretically, the reason for existence of firms is that when transactions are done inside the firm, the costs of involvement in them is less than when they occur outside and a price is dedicated by market to them (Coase, 1937; Perry, 1992; Entwistle, 2005). Actually, every firm performs some transactions inside and some outside and through the mechanism of the market. In theory, it reduces the cost of every transaction to a minimum through bringing the transaction inside the firm or else by putting it outside and through market mechanism. This, of course, forms the basis of the free market system which is assumed to be the most efficient – interpreted as the lowest cost – method for exchange to take place (Cummins & Rubio-Misas, 2006). Transaction cost needs to be at a minimum in order to provide an optimal value in the process of transformation, and accordingly, in this theory, the centre of attention of corporation's activity is on the costs related to the process of transformation. Resource depletion, of course, leads to a scarcity of raw materials, while development leads to an increasing demand for them. Thus, transaction costs can be expected to increase over time in the current environment, as firms compete for ever more scarce resources. However, what is becoming increasingly apparent is that scare resource needs to be measured in physical terms rather than monetary terms. In other words, it does not matter what the price of a raw material becomes if there is no more to be had. This has significant geopolitical implications, as those countries with the raw material can take decisions affecting their availability to others. This has potential political considerations, as the BRIC countries – especially China, India and Brazil – have policies of rapid economic development, as well as access to a large share of available resources of many raw materials (see Dubrinski, 2013; Wilson, 2015). In such a situation the market system as a medium of exchange will break down, and price will cease to be the mediating factor.

Observing countries' economy reveals that corporations are dealing, all the time, with diverting the origin of transactions through integrating and divesting. Therefore, it can be assumed that in such firms, there is an understanding of costs of transactions by the managers. Nevertheless,

Williamson[64] (1970, 1975) claims that, due to the Organisational Failure Framework, any action does not happen in an effective way because of distorted communications and bureaucracy.

Of course, while a firm is making its resource allocation decisions, its competing firms are also making their resource allocation decisions, as management strategic decision-making never happens in isolation, but always in an interactive and iterative manner. As explained in Chapter 2, this is why Game theory has become such an important decision-making tool for managers in their strategic decision-making. However, there are many problems associated with an unregulated free market.

5.3 An unregulated free market

Conventionally, economic theory has merged with political theory to believe that regulation is an unnecessary impediment to global trading (Clarke, 2004; Lipsey & Chrystal, 2015), which merely raises transaction costs and hinders trade and development. It has been assumed that the best decisions are made when left entirely to market forces to decide how resources are best employed. It might be possible to argue a case for this when there is no shortage of resources, and the assumption that financial resources are the only scarce resources, which is the basis of management theory. However, the world has changed, and sustainability has come to the fore: sustainable decisions do not necessarily coincide with decisions as to the best return on financial investment – particularly as the timescales tend to be different. Financial returns are essentially short-term, while sustainable decisions prioritise the longer term. Moreover, as resources become more depleted, they are not infinitely available; the best outcome for the world must be based on making the best use of what is available, rather than on maximising financial return. In other words, the scarce resource is no longer finance, but is raw materials, and price is not necessarily the best way of deciding upon their allocation: a sustainable world would require that distribution is equitable according to utility, rather than according to price and ability to pay. The remains of this chapter and the subsequent chapter explore this in greater detail.

[64] Williamson received a Nobel Prize for this work.

Also, Prisoners' Dilemma demonstrates that a cooperative approach is best for the world, but that this will never arise without some external intervention. Basically, all markets for raw materials are driven by the interests of buyers and sellers who are, of course, mostly commercial firms which do not share the interests of any other stakeholder. Thus, there is a potential divergence of needs and desires between economic entities and countries (and their inhabitants). After all, even Trump – with his put America first slogan – is not able to do so at the expense of the planet! This will be returned to in chapter 6, where it is argued that an unregulated free market is not sustainable in the longer run – and that resource depletion means that this longer run has arrived.

5.4 The necessity of global governance

The financial crisis of the previous decade (see section 2.12) has highlighted failures in the economic system (Klapper & Love, 2011; Claessens & Van Horen, 2015), particularly in the areas of governance and regulation (Reinhart & Rogoff, 2009). The problem with this argument is the lack of a truly global market and the ability to regulate it. However, the failures were such that the efficient market hypothesis has been argued to be invalid (see Ball 2010).

As discussed in section 2.12, regulation of financial markets is difficult. Inevitably, regulators must act in accordance with their rules, as determined by the requirement of their founders; thus, they must focus upon their area of competence, and normally consider only a local market, while finance escapes through its ability to migrate around the world. Of course, one consequence of this regulatory failure is that contamination spreads, and the practices developed in one financial market become the norm in other markets (Celik, 2012). When the inevitable crisis appears, this too spreads from one country to another, as all economies are affected by both the consequences of dubious lending practices and the ensuing crisis of confidence. This calls attention to the fact – recognised but mostly ignored in the financial models (e.g. the efficient market hypothesis, Malkiel, 2003) – that the financial market is a global market, and a corollary of this is that any regulatory regime must also be global. Therefore, this highlights the problems with the current regime and argues that perhaps a global regulatory authority, capable of sanctioning even the most powerful actors in the market – including national and transnational governments – is necessary in the current global environment. Certainly, any market seems to need some form of regulation in order to operate

satisfactorily, and preferably also, efficiently. Again, this is something which is considered in detail later.

5.5 Application to real data

Chapter 4 illustrated the theoretical developments and implications of the model. Although their robustness has been shown, it is still required that the model be tested with real data to provide more verification, and also for triangulation. The remaining of this chapter incorporates such testing. As explained in Chapter 3, for this analysis, five data sets are being used:

- Gross World Product (GWP) and Gross Domestic Product (GDP);
- The oil industry;
- The tin industry;
- The lead industry;
- The copper industry.

Subsequently, data from individual companies' published accounts will be used.

These are all industries in which scarcity of available mineral for extraction are expected to become apparent. The global GWP and GDP data has been applied to the three countries: UK, Malaysia and Iran, and the industry data has been applied to the global industry and to individual firms. This is all detailed in the relevant sections below.

The global GWP and GDP data has been used for two main reasons: firstly, for triangulation, and secondly, to show that the model is valid for analysis at any stage – national or industry level. Thus, analysis will start with the meta stage, and in this stage, the data in national level will be tested.

5.5.1 Global economic product

Here, it is required to utilise the national GDP data. Obviously, national GDP data is accessible through public domain. The estimation of the World Bank[65] is that the whole global gross domestic product - which is known as GWP - is shown in Table 2.1

Unsurprisingly the largest national GDPs in 2019, as calculated by IMF and World bank are:

		$US billion	**$US billion**
WB ranking		**IMF estimate**	**World Bank estimate**
	GWP	87265	87751
1	USA	21439	21427
2	China	14140	14342
3	Japan	5154	5081
4	Germany	3863	3845
5	India	2935	2875
6	UK	2743	2827
7	France	2707	2715
8	Italy	1988	2001
9	Brazil	1847	1839
10	Canada	1730	1736
25	Iran	458	Not available
33	Malaysia	365	364

Table 5.1 – The biggest national gross domestic products in 2015[66]

[65] http://databank.worldbank.org/data/download/GDP.pdf accessed 21/7/2016
[66] https://en.wikipedia.org/wiki/List_of_countries_by_GDP_(nominal)

Something noteworthy is that these two organisations do not give the same figures for countries (see section 3.15). The only country in which the figures are more similar is the USA, but even in that country the figures are different by about $21 billion – although such variation could be much bigger about any other country in the list. The reason is the margin of error in the calculation of these numbers. All countries calculate their gross domestic products, and then, issue them in public domain. Afterwards, these organisations make adjustments, while they trace the coherence regarding year and country. However, it is shown above (sections 4.8 & 4.9) that the regulation cost is below one percent, and therefore, not noticeable in such error margin.

Obviously, there is no supranational regulating of gross domestic product and worldwide economic interactions. There are bodies such as the World Bank or WTO, who act as negotiators to help a smooth global trade, although they do not play an important role in regulating. Accordingly, it would just be reasonable to apply a very large value for regulation, and then, measure the outcome. Thus, the number considered here is one percent. This figure has been used for the gross domestic products of the UK, Iran, and Malaysia. Figure 5.2 shows particulars of the gross domestic product as per 2019 for the three countries as follows[67]:

	UK	**Malaysia**	**Iran[68]**
GDP (US$billion)	2827	365	445
Growth in last year (%)	-2.2	-2.0	1.8
Per capita GDP (US$)	43688	12110	6952

Table 5.2 – Country GDP statistics for 2019

5.5.2 Considering the assumptions made

It is accepted that a number of factors will affect the cost of production of minerals. These factors are related to technological development in both extraction of minerals and processing them for distribution. Also, it is accepted that as the mineral becomes scarcer, then it will

[67] Source = www.tradingeconomics.com. There are several different sources for each country, but this one is used for comparability, as it is based on World Bank figures.

[68] International sanctions have seriously affected GDP for Iran since 2012, and this had led to drastic falls in GDP and per capita GDP. The relaxation of these sanctions can be expected to result in that GDP regrowing to pre-sanction levels.

become more difficult to extract the remaining mineral. This is because the mine will probably be located in more difficult areas, either geographically or physically. However, it is argued that these factors will be unaffected by the choice of distribution method – through the market pricing system or another method – and so can be ignored in this analysis. It is further acknowledged that geopolitical factors discussed previously will affect availability of minerals, and these may be affected by choice of distribution method. However, if these geopolitical factors significantly affect availability and distribution, the world will not be in a sustainable situation, and so, taking these into account in the analysis would not be relevant in determining which method is best for a sustainable world.

It is further accepted that as a mineral becomes scarcer in availability, then the transaction costs involved in locating and acquiring sufficient quantity will rise. This is because more effort needs to be expended by the acquiring company in locating, transporting and storing the mineral. However, it is argued that these factors will not be significantly affected by the distribution method adopted, as this will be determined by external sources (see chapter 6).

It is now possible to go back to the model in chapter 4, and apply the real data in the resulting statement. This has been formulated so that a negative value shows that collaboration is the better alternative, while a positive value shows that competition is better:

$$(rz^2 + rez^2 - ez^2)/2 - xz^2/2 < 0$$

Where:

“e” is the efficiency gains in use of resources due to cooperation;
“r” is the regulation costs;
“z” is the change in total capacity of production;
“x” is the competition costs.

Here, the original assumption, i.e.: x = e is still held, and the inequality will become:
$(rz^2 + rez^2 - 2ez^2)/2 < 0$

These figures are not recognised separately in accounting of governments, as cost of regulation and efficiency gains from collaboration do not exist in the current market environment.

Therefore, it is necessary to make assumptions about their size, and one has to consider that such figures are very small; it is claimed by Klemperer (1995) that such figures incorporate a combination of competition costs, as explained below and generally comprise below one percent of the whole costs.

Thus, actual figures to put in the formula are the maximum values expected, which are:

r = 1.0%
x = 1.0%

Here again, z^2 can be omitted from the formula. The resulting inequality is therefore:

$$(r + re - 2e)/2 < 0$$

By inserting the actual figures:

$$\big(0.01 + 0.01 \times 0.01 - 2(0.01)\big)/2 = -0.0495$$

As can be seen, this figure is negative, therefore the analysis holds true.

Because of uncertainty about the actual figures, an investigation among feasible range of data is needed. In order to do so, it is necessary to set values which are at the extremes of the credible range for cost of regulation. Accordingly, the extreme of credibility for the smallest and largest possible figures could be 0.05% and 2.5%, respectively. As a result, the analysis is checked by triangulation through these figures. Inserting the figures leads to the following:

Inserting r = 0.05% leads to a negative figure as: – 0.0004975;
While inserting r = 2.5% leads to a negative result as – 0.024375 as well.

Consequently, one can observe that among all the feasible range of costs of regulation, the value is always negative. As a result, the theoretical calculation is supported by the actual data, and could be considered as proved properly – at least for all realistically conceivable costs of competition. It is noteworthy that such numbers and their effects are vastly unnoticeable due

to margins of error. In other words, the errors in the calculations of GDP are, probably, larger than any costs of regulation. This suggests that cost should not be any impediment to imposing regulations in order to encourage a collaborative approach. This will be returned to in chapter 6. However, because of the margin of error, using data from companies for further testing becomes important.

5.5.3 Sensitivity analysis

In order to undertake a full sensitivity analysis, to find what range of values would make the calculation show a different outcome, it is necessary to look at the equation and calculate some values. Thus, it would be necessary to show values at which the equation value exceeds zero, and therefore, it is possible to start by calculating the value at which the equation outcome equals zero:

$$r + er - 2e = 0$$

With 2 variables, this can, of course, only be solved in tabular form.

Solving for e with r as fixed gives the following:

Regulation cost % of total cost	**Efficiency gains % of total cost**
0.5	0.25
1	0.50
2	1.01
10	5.26
20	11.11

As argued in section 4.9, the cost of regulation excluding any political interventions is unknown but is almost certainly < 2%, and probably < 1%. This would mean that gains from collaboration would need to be in the range of <1%, and probably < 0.5%, in order to satisfy the equation. Moreover, the semi-fixed nature of the cost of regulation means that as the mineral becomes scarcer in supply, the unit cost of regulation will rise. It should also be

recognised that the regulation under consideration does not exist at the moment, nor does the efficiency gains from collaboration, and so figures are difficult to prove. It should also be recognised that small efficiency gains are difficult to establish because of measurement difficulties. It is also a factor to be accepted that if there were significant benefits from collaboration, then these would have been recognised already, and the economic market would have become organised differently.

Taking efficiency gains as the determining factor, and regulatory costs as the variable gives a similar picture; This shows that regulatory costs would need to be unreasonably high in order to make the relationship false. For example, efficiency gains of 2% would require regulatory costs to exceed 3.92%, while efficiency gains of 10% would require regulatory costs exceeding 18.18%. Such values would, of course, be politically unacceptable as well as unnecessary when estimates are below 2%.

Efficiency gains % of total cost	**Regulation cost % of total cost**
0.5	0.99
1	1.98
2	3.92
10	18.18
20	33.33

On that basis, therefore, the next step is to look at actual data for industries and firms to determine the actual situation.

5.6 Tin industry data

The largest tin producing companies are as follows:[69] [70]

[69] https://www.itri.co.uk/index.php?option=com_zoo&task=item&item_id=2717&Itemid=143 accessed 13/7/2016

[70] ITRI lists the companies in this order in terms of production levels.

Company	Domicile	2010 Tonnes	2015 Tonnes	Market share %
Yunnan Tin	China	59180	75500	21.9
PT Timah	Indonesia	40413	27431	8.0
Malaysia Smelting Co	Malaysia	38737	30260	8.8
Minsur	Peru	36052	20224	5.9
Thaisarco	Thailand	23505	10502	3.0
Guangxi China Tin	China	14300	11100	3.2
Yunnan Chengfeng	China	14155	16600	4.8
EM Vinto	Bolivia	11520	12106	3.5
Metallo Chimique	Belgium	9945	8863	2.6
Geju Zi-Li	China	9000	11000	3.2

Table 5.3 – The biggest companies producing tin

The market size in 2015 in monetary terms is equal to 7.4 billion dollars. Supply varies as described above, as does demand. This means that price fluctuates considerably; for example, the average price per tonne of tin was $21,686 in 2014, but reduced to $16,186 in 2015, and recovered to $20,750 in late 2016. Thus, there is some pressure on companies to compete through price and through the stimulation of demand.

Finding data, especially for Chinese companies is problematic because reporting tends to be in Chinese. As a consequence, data has been collected for the largest two companies not domiciled in China. These are PT Timah (domiciled in Indonesia), and Malaysia Smelting Co (domiciled in Malaysia). It is argued that the data for every company is similar in nature, and the selection of any other companies would show similar results.

The company which exclusively deals with tin in Malaysia is the “Malaysia Smelting Co”. Therefore, it can be a good example to be used for analysis. The following shows the annual account of this company:

	2015	**2014**
	RM'000	**RM'000**
Revenue from mining etc	1,464,855	1,915,179
Costs of operations	1,328,548	1,768,676
Gross profit	136,307	146,503
Other income (loss)	(47,933)	(5)
Employee benefit expenses	49,782	51,258
Finance costs etc	30,077	18,517
Share in net income of associates	1,683	1,995
Finance income	8,673	16,555
Other expenses	6,960	16,246
PBIT	3,238	44,992

Table 5.4 – Malaysia Smelting Corp. financial summary

The company has declared their core values as:

- Being intellectually of integrity and honest;
- Being respectful to employees' safety, health and environment;
- Having a spirit of competitiveness and global perspective;
- Developing sustainable value for shareholders by effective activities;
- Creating added value by continual improvement and innovations.

This way, the company expresses their awareness of sustainability requirements.

Competition costs are included in "other expenses", which totally encompasses 0.49% of costs. Therefore, it can be reasonably suggested that competition costs consist below half of this figure: so it is at most 0.2% of the whole costs.

No other significant companies exist within the three countries chosen for analysis; therefore, the largest other company[71]– an Indonesian one – has been selected for analysis. PT Timah is

[71] Chinese companies have been ignored in all the analysis because there is limited information in English available about them.

the largest mining company in Indonesia. It is a state-owned enterprise which took over operation from the Dutch East Indies government 40 years ago. Basically, it is only concerned with tin mining and smelting, which accounts for 95% of its business. Its accounts show the following information:

	2015	**2014**
	Million Rupiah	**Million Rupiah**
Revenues	6,874,192	7,518,010
Cost of Revenues	6,188,183	5,902,716
Gross profit	686,009	1,615,294
General & administrative expenses	515,352	596,752
Selling expenses	89,160	55,613
Finance costs	129,296	111,964
Share in net income of associates	6,713	96
Finance income	8,673	16,555
Other income	200,576	157,228
Operating expense	517,846	590,450
PBIT	168,163	1,024,844

Table 5.5 – PT Timah financial summary

For this company, costs of competition fall within the "general and administrative expenses", and these account for 7.4% of total costs. No breakdown of this figure is provided, but obviously, it contains many more items than the "other expenses" of Malaysian Smelting Co. On that basis, therefore, it has been assumed that costs of competition comprise at most 1% of total expenses.

Although tin market is not governed by any regulatory organisations, but ITRI is a trading association that performs regulatory activities as well as other functions (see 3.17.2). This firm, which is limited by guarantee, has been registered in 1994. The latest accounts available show the following:

	$'000
	2012
Revenue	2178
Cost of goods sold	1463
Gross profit	715
Selling, general and administrative expenses	336
Depreciation, R&D etc	228
Operating income	151

Table 5.6 – Financial Summary of ITRI

Total cost of the firm comprises 0.25% of the market, of which, the regulatory costs should be below a third[72]. This represents a maximum of 0.1% of the turnover of industry.

Accordingly, using the analysis in chapter 4, it is possible to insert real data in the inequality as follows:

$(rz^2 + rez^2 - ez^2)/2 - xz^2/2 < 0$

Where:

e = gains in resource utilisation efficiency as a result of collaboration;
r = regulation cost;
x = competition cost;
z = the overall capability of production.

Here, the original assumption that x = e is still held, and the inequality will become:

$(rz^2 + rez^2 - 2ez^2)/2 < 0$

Here are the real values to be inserted for Malaysia Smelting:

r = 0.1%

[72] The company describe their main functions as technological development, organizing conferences, marketing, as well as performing regulatory duties.

x = 0.2%

it is again possible to omit z^2 in the inequality.

Thus, the resulting statement will be:

$$(r + re - 2e)/2 < 0$$

After inserting real data:

$$\big(0.001 + 0.002 \times 0.001 - 2(0.002)\big)/2 = -0.001999$$

As can be seen, this figure is negative, therefore the analysis holds true (as per 5.5.2 above). The theoretical calculations are supported by real data, and it can be considered as proven.

Duplicating this calculation with the PT Timah data gives the following:
r = 0.1%
x = 1.0%

$$\big(0.001 + 0.001 \times 0.001 - 2(0.01)\big)/2 = -0.001495$$

This is also negative to a similar level, so confirms the proof above.

In order for the results to be untrue, the cost of regulation would need to exceed 4%. Such a value would be in excess of any politically acceptable value, and therefore, the process of regulation would need to be changed. All current evidence suggests that this would not be possible. Thus, the data shows that the equation holds true at all feasible values.

5.7 Lead industry data

Approximately, 5.4 million tonnes of lead are mined each year[73], with 52% coming from China – which also accounts for 42% of global usage. The average price of lead in 2015 was $1.82

[73] http://www.bgs.ac.uk/mineralsuk/statistics/worldArchive.html accessed 6/8/2016

per tonne, giving the value of the global market as $9828 million per annum. 80% of current usage is in the production of batteries.

There are no significantly global companies which are just concerned with lead mining. Instead, large international conglomerates dominate the market. Consequently, no information for just lead companies exist, and so three of the largest companies have been investigated, and it is assumed that the data approximately pro rates to lead mining. The three companies investigated are BHP Billiton, Rio Tinto and Anglo American; all are (or originally were) UK companies, although their operations are no longer within the UK. Financial information reported is:

	BHP Billiton	**Rio Tinto**	**Anglo American**
	$'million	**$'million**	**$'million**
Trading income	44636	34829	20455
Total expenses	37010	27919	18417
Other operating expenses included	1276	1062	1422
Profit from operations	8670	3615	2038
Profit before taxation	8056	(726)	1193

Table 5.7 – Lead industry companies' financial summary

Costs of competition fall within the "other operating expenses" headings. Also, within this figure are costs for such things as administrative staff, marketing costs, accounting costs, etc, depending upon how each company prepares its accounting. The actual figure is not known and is never calculated, being absorbed within other costs heads. Therefore, it must be estimated, and any reasonable estimation would state that such costs must account for significantly less than one third of this figure. On that basis, the costs of competition account for 1.1%, 1.3% and 2.6%, respectively, for the three companies. Thus, a figure of 1.5% has been used for the calculations below, as this is considered to be a generously large figure.

Again, there is no regulatory body, but there is a trade association. The International Lead Association (www.ila-lead.org) – based in London – acts as a trade organisation, and is

concerned with social responsibility and environmental responsibility, as well as with recycling. It claims that:

> Its mission is to promote and defend the responsible production, use and recycling of lead to create and sustain conditions in which business can compete and prosper.

It gives a high priority to regulatory affairs, perhaps because lead is so toxic. It is a private company limited by guarantee and without share capital. Therefore, it does not publish its annual accounts, but has a declared turnover of £1,310,000 in 2015[74]. Regulatory affairs have greater predominance for this industry than for the tin industry, and so it would be reasonable to assume that 50% of the turnover is connected with this rather than trading and research activities. On that basis, this represents 0.007% of industry turnover – a very small amount.

Applying the same calculations and substituting in the formula:

$(r + re - 2e)/2 < 0$
where:

x = costs of competing = 1.5% = 0.015
e = gains in efficiency of resource utilisation from collaboration = x = 1.5% = 0.015
r = costs of regulation = 0.007% = 0.00007
so the inequality becomes:

$$\big(0.00007 + 0.015 \times 0.00007 - 2(0.015)\big)/2 = -0.014964475$$

The figure is again negative, which demonstrates the validity of the argument.

5.8 Oil industry data

Undoubtedly, oil is a vital industry in Iran and is the basis for the economy and finance of government. Oil is an important industry for Malaysia as well, where it has substituted tin in

[74] http://www.endole.co.uk/company/00417640/international-lead-association?page=financials accessed 16/8/2016

their economy. However, although oil is important for the UK as well, the degree of such importance is quite lower. The size of this industry is so big, and the whole sum of turnover in 2015 was 12569 billion dollars. The largest oil companies of the world are shown in Table 3.2 but repeated here for convenience:

	Firm	**Revenue (1000 million dollars)**	**Country of domicile**
1	Saudi Aramco	478.0	Saudi Arabia
2	Sinopec	455.5	China
3	China National Petroleum Corp	428.6	China
4	PetroChina	368.0	China
5	Exxon Mobil	268.9	USA
6	Royal Dutch Shell	265.0	Netherland / UK
7	Kuwait Petroleum Corp	251.9	Kuwait
8	BP	222.8	UK
9	Total SA	212.0	France
10	Lukoil	144.2	Russia
19	Petronas	100.7	Malaysia

Table 3.2 – Details of the biggest oil producing companies

It can be seen that many of these are government or government related companies from the largest oil producing countries – particularly, Saudi Arabia and China. Such companies, particularly, the Chinese domiciled companies are not really suitable for use in this analysis; this is because their accountings are not necessarily produced according to international standards, and because the Chinese and Russian companies do not bother to report in English. The ease of performing business in terms of regulatory practices, which either limit or improve doing business in at least 180 regions of the world, is evaluated by the Ease of Doing Business report of The World Bank[75]. The report ranks 10 areas of business activity from starting a

[75] http://www.doingbusiness.org/rankings accessed

business, registering property, getting credit, import and export regulations and procedures, protecting investors, enforcing contracts to resolving insolvency. The 2018 report shows:

1	New Zealand
2	Singapore
3	Denmark
6	USA
8	UK
12	Malaysia
28	Russia
31	China
32	France
62	Saudi Arabia
127	Iran

Table 5.8 – Ease of Doing Business summary

Two companies are selected for analysis from the countries under consideration – although it is argued here (as elsewhere) that different companies would show similar results. Therefore, those chosen are BP from UK and Petronas from Malaysia. Iran is too recently reconnected to the global trading network, and reliable and stable figures are not available.

Due to sensitivity of the oil industry owing to the geopolitical area the industry is situated in, related governments monitor it watchfully. This is a significant kind of regulation, although just at the national level. Majority of countries treat it as a basis for tax revenue as well. Therefore, it is not possible to measure precise value for real regulation cost due to lack of any global regulatory body, and also because of associating costs to tax revenue instead of regulation.

Besides, there are numerous trading associations – which represent either interests of one country or firms inside that country, or interests of a region. Examples are given in Table 3.4. Thus, obviously there is not any global regulating organisation or any trading association claiming interests of the world. Therefore, there is not any figure for costs of global regulation;

regulatory practices are mainly to enhance tax revenue, or to support national interests as discussed before. Accordingly, it is sufficient to do investigation only about two companies within the industry, and to extrapolate for the whole industry. The financial position of the companies for 2015 was as follows:

	BP	**Petronas**
	$ million	**RM million**
Total revenue	225982	247,657
Total expenditure	233900	284,340
Profit before interest and taxation	(7918)	36,683
Distribution and administrative expenses	11553	27,570

Table 5.9 – Oil company financial summaries

For these companies, as is normal everywhere, the regulation costs are included in the costs for administration and distribution, totally comprising 4.9% and 9.7%, respectively, of the whole turnover. “Distribution and administrative expenses” also include costs such as those for human resources, premises, finance and legal, logistics and some other costs related to administrative functions. Thus, costs of regulations should not account for above 10% of this amount. As the firms on their own do not record costs in a format to enable reaching a precise figure for cost of regulation, so these costs must be assumed from within this analysis. Therefore, a figure of 0.5% is assigned for the regulation costs, and then, through triangulation, a range of one forth to four times of that has been analysed. Costs of competition are also contained within the same figure, and given the nature of all the other costs, it is equally unlikely that they will comprise greater than 10% of the total. Thus, it is considered reasonable to apply the same figure of 0.5% to this also.

By inserting the evaluated figure of 0.5% in the resulting inequality:

$$(rz^2 + rez^2 - 2ez^2)/2 < 0$$

Here are the real values to be inserted:

r = 0.5%
x = 0.5%

it is again possible to omit z^2 in the inequality.

Thus, the resulting statement will be:

$$(r + re - 2e)/2 < 0$$

After inserting real data:
$$\big(0.005 + 0.005 \times 0.005 - 2(0.005)\big)/2 = -0.004975$$

As can be seen this figure is negative, therefore the analysis holds true.

Applying the numbers considered for triangulation leads to:

Inserting r = 0.0125% leads to - 0.0123438, which is negative;
Inserting r = 2% leads to – 0.0196, which is again a negative figure.
So, as can be seen, among all possible range of data, the result is a negative figure; thus, the calculations are robust.

5.9 Copper Industry data

The global production from mining of copper in 2018 was 21 million tonnes, of which 28% was mined in Chile. This amount has been growing annually, and has increased by 22% since 2012[76]. Copper – like many minerals – is produced by large companies engaged in the mining of multiple minerals. The largest companies involved are:

BHP Billiton
Rio Tinto
Xstrata – now Glencore
Freeport Mcmoran

[76] http://www.world-mining-data.info/wmd/downloads/PDF/WMD2018.pdf accessed 12/10/2019

Anglo American
Antofasta
Norisilk
Inmet Mining
Southern copper
Teck

BHP Billiton, Rio Tinto and Anglo American have already been analysed above.
The next biggest is Glencore and the accounts show:

	2018 **US$ million**	**2017** **US$ million**
Revenue	219754	205476
Cost of goods sold	(210698)	(197695)
Selling and administrative expenses	(1381)	(1310)
Other expenses	(764)	34
Net income	6911	6505

Table 5.10 – Glencore financial summary

Costs of regulation are included within the "selling and administrative expenses", and these in total comprise 6.5% of total costs. Selling and administrative expenses also include costs such as those for human resources, premises, finance and legal, logistics and some other costs related to administrative functions, in addition to costs of selling. Thus, costs of regulation should not account for above 10% of this amount. As the firms on their own do not record costs in a format to enable reaching a precise figure for cost of regulation, so these costs must be assumed within this analysis. Therefore, it is reasonable that a figure of 0.5% is assigned for the regulation costs. Costs of competition are also contained within the same figure, and given the nature of all the other costs, it is equally unlikely that they will comprise greater than 10% of the total. Thus, it is considered reasonable to apply the same figure of 0.5% to this also.

By inserting the evaluated figure of 0.5% in the resulting inequality:

$(rz^2 + rez^2 - ez^2)/2 - xz^2/2 < 0$

Here are the real values to be inserted:

r = 0.5%
x = 0.5%

it is again possible to omit z^2 in the inequality.

Thus, the resulting statement will be:

$(r + re - 2e)/2 < 0$

After inserting real data:

$\big(0.005 + 0.005 \times 0.005 - 2(0.005)\big)/2 = -0.004975$

As can be seen, this figure is negative, therefore the analysis holds true.

Applying the numbers considered for triangulation leads to:

Inserting r = 0.0125% leads to - 0.0123438, which is negative;
Inserting r = 2% leads to – 0.0196, which is again a negative figure.

So as can be seen, among all possible range of data, the result is a negative figure; thus, the calculations are robust.

It would be possible to repeat this analysis with any, or all, of the companies involved, and also to repeat the analysis for other industries concerned with the extraction of other minerals. However, it is argued that the results would be the same. It must be recognised, however, that precise figures are never calculated for costs of regulation or of competition. However, mere observation of company financial statements indicate that the figures of concern are all in a similar range; indeed, figures outside this range would be considered so unusual that they

would arouse concern amongst auditors as well as investors. On this basis, therefore, it is argued that further analysis of company financial statements would only produce similar results which verify the analysis.

5.10 Sensitivity analysis considerations

The calculations for each industry show similar results for the industries as a whole and for the individual companies considered. It also applies to the three country economies which have been considered. Therefore, the question arises as to whether the countries, industries and firms chosen are sufficiently diverse to consider them to be a representative sample of the global economy, and therefore, to be satisfactory to apply the findings generally. Certainly, the three countries chosen are very diverse, and so that does not seem to be a problem. As far as the industries are concerned, then these are a sample of the extractive industries in which, resource depletion is becoming apparent, and therefore, it is argued that these also are representative. As far as the individual firms are concerned, then these are all among the largest in their respective industries. The nature of the extractive industries is that large firms are most efficient and most sustainable, and all major firms tend to be large – in the case of oil, they are all very large. It is also true that the costs of regulation will fall proportionately more heavily on smaller firms, and this could possibly change the analysis. Having said that, though, all firms in these industries need to be large in order to have the capital necessary to undertake the necessary exploration, mining, extraction and refining that is required. Therefore, it is argued that it is not really necessary to perform analysis for various different sized firms to see if this changes the analysis. Nevertheless, the potential difference needs to be considered, and is appropriately so considered in this chapter.

The calculations using actual data confirm those calculated theoretically in the preceding chapter, and therefore, seem to confirm the argument that it is better for companies and also for the world economy to collaborate. This is also intuitively correct, as it eliminates the need to compete for increasingly scarce resources. However, in order to be absolutely certain, it is necessary to undertake some form of sensitivity analysis in order to understand if this proof holds for all likely values and conditions of these and similar industries.

The data used is representative of all firms in all industries, and it is argued that selecting other industries and other companies would yield the same results. Thus, the issue of replicability is addressed. The calculations have been shown to be robust, and therefore, the model is sound. It is apparent from looking at the maths that the argument will always hold true as long as the efficiency gains from collaboration exceed the costs of regulation. In the preceding analysis, a wide range of possible values have been considered and all show this to be true. Unfortunately, in terms of global trade, the costs of regulation and the benefits from collaboration are too small to be ascertained accurately, and for GDP are less than the statistical error contained within the figures. Of course, this does not invalidate the calculations regarding the analysis and argument. Furthermore, it is necessary to emphasise that as the resources become more depleted or scarcer in relation to increasing demand, then the relative cost of competition from increased demand for restricted supply inevitably raises transaction costs. Therefore, the significance of these findings will become more apparent as time progresses. Geopolitical aspects also start to matter, and this is dealt with in chapter 6.

Moreover, the current economic model of trading is based upon competition, and the data for the effects of collaboration does not really exist. It has been necessary to make assumptions and extrapolations to work out the effects of a collaborative system which would effectively imply a new economic system. Again, the implications are considered further in chapter 6. Additionally, very little research has been undertaken into the effects of regulation. However, having said this, in the USA, the Office of Management and Budgets reported to Congress[77] that the costs of regulation in the economy were between $68.5 billion and $101.8 billion, while the benefits accruing were between $260.9 billion and $981 billion. These figures are disputed by various trade organisations which have a vested interest in reducing the cost of regulation. It can also be estimated that these costs are significantly higher than would be the case in the rest of the world. Nevertheless, it seems clear that the benefits outweigh the cost of regulation to a noticeable extent, but no comparable research seems to exist elsewhere.

On this basis, therefore, it seems reasonable to argue that the data supports the mathematical calculations to show that collaboration is better than competition. The implications of these findings need to be considered, and this is the subject matter of the subsequent chapter.

[77] https://cei.org/10KC/Chapter-1 accessed 16/8/2016

While a firm is making its resource allocation decisions, competing firms are also making their resource allocation decisions: management strategic decision-making never happens in isolation but always in an interactive and iterative manner. As explained in Chapter 2, this is why Game theory has become such an important decision-making tool for managers in their strategic decision-making. However, there are many problems associated with an unregulated free market. Again, this will be discussed further in chapter 6.

5.11 Chapter summary

In this chapter, the mathematics developed in the previous chapter have been tested using actual data from GDP, industry and company reporting. The sensitivity of the calculations to changes in the data have also been considered to show that it is not really sensitive and holds true for all reasonably expectable values which might exist. The robustness of the theoretical developments in this and the preceding chapter seems apparent. Due to lack of any model comparable to assess sustainability in the same way, this model is checked by means of real data. In order to do this, various data sets have been applied through which the robustness of the model is shown.

The findings of this chapter have several implications, both theoretically and practically. The implications for governments and corporations from the findings are noticeable. These will all be considered further in the next and the final chapters. The next chapter considers the implication of the findings for the world economy, in terms of sustainable distribution of the depleted minerals, while the last chapter considers the application of this research on a general basis, according to the contents of the current chapter.

Chapter 6

Discussion

6.1 Introduction

The analysis in the preceding chapters has shown that the best approach to dealing with sustainability – as far as the world as a whole is concerned – is the collaborative approach. As the world is changing so that mineral resources become scarce, and eventually totally used, it is necessary to make optimum use of what is available. There are two parts to this. Firstly, the future becomes more important, because if the mineral is used in the present, it is no longer available for the future. Secondly, price alone does not decide the optimum allocation of the resource. For sustainability, the question of equity becomes more important, as explained below. The analysis in the preceding chapter shows that the most effective way to achieve this equity is through a collaborative approach, with countries and firms reaching agreement on how to achieve this equitable distribution. As discussed in chapter 2, previous research has reached no agreement that minerals are becoming depleted. It has not addressed the problem of how to deal with this issue, even though it cannot be disputed that the available supply of any mineral is fixed, and once used, is not available for future use – other than through recycling.

It is also recognised that the entire economic foundation of the world and its markets is based upon a competitive approach. At the same time, the pricing system assumes that the best outcomes for individual firms – operating in isolation – is a competitive approach, and that this is also the best outcome for countries and for people. This thesis argues that this no longer works, and that collaboration will lead to better outcomes for the sustainability of the world. However, the application of Game theory indicates that the collaborative approach will never arise without some form of external intervention, which requires some kind of international agreements. The implications of this are considered in this chapter.

6.2 Global sustainability

It has been argued previously that one of the platforms of sustainability is equity. Thus, many (see Padilla, 2002 for a summary) have argued that intergenerational equity needs to be taken

into account to achieve sustainability. However, Rogers (2014) argues for socioeconomic equity as a precursor to achieving sustainability. Others have also considered sustainability and access to mineral deposits. Thus, Giurco & Cooper (2012) argue that recycling is more important, but fail to address the issue of the finite amount of available mineral. Mudd & Ward (2008) argue that mining is essentially unsustainable because of the finiteness of resources. A few (e.g. Christmann, 2012) have argued that sustainability requires equity in access to resources, particularly critical resources. Thus Richardson (2003) has shown that the emergence of collaboration through regulation, among a small number of countries, can assist equitable access. Similarly, Henckens et al. (2016a) have argued for the establishment of international agreements on the restriction of extraction to extend their future availability for future generations; similarly, Ali et al. (2017) argue that governance is essential for sustainability. Others (e.g. Addison et al., 2002) have highlighted the consequence of lack of access becoming armed conflict. Therefore, there is an emerging consensus that achieving sustainability requires equitable access to resources.

Equitable access to the remaining resources requires that they be extracted from the earth, and then distributed in an equitable manner. This means that they need to be distributed according to need (i.e. use value) – rather than according to economic demand – as this would simply mean that price would be set so that the richest could acquire all the available resources. This would inevitably lead to conflict. This research has investigated the best way to distribute the mineral resources that are extracted. This is achieved through answering the research questions posed, and then considering the implications of the analysis.

6.3 Research questions answered

The analysis undertaken in the preceding chapters have shown that a collaborative approach to the distribution of resources is preferable to a competitive approach. This requires a different approach to allocation through the market, and can be considered in terms of answering the research questions posed.

1. Does resource depletion have an impact upon the way firms acquire the resources for their production, and if so, then how?

It is recognised that technological changes are taking place in the mining industry, and these will effect how minerals are extracted and processed. It has been also recognised that technological changes are taking place which will effect what minerals are required and in what quantity. However, it has been argued that these do not affect the available quantities of minerals, and also that price changes will have a limited effect upon demand. In other words, as scarcity increases prices, this does not cause more mineral to be mined as supply is restricted. Moreover, the quicker it is mined, then the sooner all will be exhausted, even though it is currently uncertain how much remains to be extracted. However, sustainability requires that attention be paid to how quickly the mineral is extracted and how it is distributed throughout the world. Indeed, sustainability requires that it be distributed equitably according to use value – rather than according to a market pricing system in which, the richest acquire the greatest share. Thus, it can clearly be seen that depletion of resources is having / will have an impact upon how, and also upon the quantity, firms can acquire for their production processes.

2. What changes are needed to address the issue of depletion for sustainability in the global market?

The answer is:

A) With a fixed quantity of each mineral available upon the earth resulting in the depletion of many of them, then the crucial question as far as sustainability is concerned is the use to which the remaining mineral is put. This must be considered in terms of both what use is made of the extracted mineral and the speed at which the remaining quantity is extracted. Obviously, the more is extracted at any time, the less remains for future use.

B) Sustainability, of course, must consider the future as much as the present, and must plan for future generations also. This would imply a global approach to the use of each mineral and moves the problem into the political arena, and so outside the scope of this thesis.

C) However, it does seem clear that distribution of the mineral extracted is more significant, for a sustainable future, than is the technology for extraction.

3. Would a new approach to the global management of distribution of planetary resources be beneficial?

The answer is yes. The research undertaken in this thesis shows that it is more effective – from a sustainable perspective – to adopt a cooperative approach to distribution of the minerals – rather than a competitive approach. This implies that the current market system based upon distribution being determined by price needs to be altered. It has also been argued that the maintenance of an equilibrium market based upon supply and demand being mediated through price is no longer appropriate. This is because – in this situation – only demand can be flexed according to price as supply cannot realistically be increased as price rises. In fact, it has been argued that mediation needs to be through use value rather than price, because price mediation results in the richest acquiring the available resources, and this does not lead to sustainability – quite the reverse.

4. What kind of interventions, if any, are needed for effective management of the resources of the planet?

Game theory has shown that the required changes will not happen automatically, and some intervention is needed. If the distribution of any minerals extracted is to be determined according to need rather than price and demand, then there is a need for some form of regulation of the market. This can be considered to be a significant intervention that is necessary, and the implications of this are discussed below.

6.4 Identifying a dilemma

This thesis argues that the player should adopt one of the two strategies possible: either to cooperate or to compete. Although the best outcome in a simple situation is always achieved through competing, Axelrod (1984) and Erev et al. (2007) inter alia have argued that, in a continuing Game series, the optimum outcome is always arrived at through choosing the strategy last taken by the opposing player. This results in all moves tending towards being either all competitive or all collaborative. Although any player can adopt competition in order to gain a short run achievement, the analysis shows that collaboration is more effective in the long-term – both for the player and for the world. In a non-zero sum Game, the strategies have been considered in an environment in which total payoffs can be increased; as a consequence in this game, an increase in payoff for one player is not necessarily at the expense of other players. However, in the era of depleted resources, the total payoff is reducing, and the payoff for each player is reducing without any competitive actions from the other players. Indeed,

competition raises transaction costs, and thus, reduces the resources available for production. Thus, one firm might be able to increase production through competing for resources, but the effect is a net reduction in resources available for the world. The consequence of this is to give a big incentive to all players to improve their rewards at the expense of other players, merely to stand still. Thus, competition is engendered by the nature of the game, and this makes it even harder for a collaborative approach to be introduced and work successfully – hence, even more need for external interventions to manage the market place. The scenario taken in this thesis is that when resources of the world are depleting and getting scarcer, then the situation is one of a reducing outcome game. This changes strategy as described by Kotler et al. (2002) to show that collaboration is needed.

This presents a dilemma for the modern world. Current economic theory and ideology shows that competition is the best way to expand – both for an individual firm – and therefore for nations and ultimately, for the world and all inhabitants. Thus, development is considered to be desirable. This economic model is based upon the Prisoners' Dilemma scenario (Axelrod, 1970) whereby individuals gain advantage through competing with others. Some (e.g. McAdams, 2008) argue that this is somewhat simplistic, without really offering any variations. Indeed, Amadae (2016) argues that the whole foundation of neoliberalism is based upon Game theory, and particularly, the Prisoners' Dilemma. Others (e.g. Kuhn & Moresi, 1995; Gibson, 2003) argue that it is merely an extension of Utilitarianism. Nevertheless, the game, as described in this thesis, is significant in aiding knowledge about the impacts of depletion of resources.

The evidence suggests that such a kind of game has not been considered for the world as a whole, although Coelho Filipe & Ferreira (2011) consider fishing in international waters and the problems of transboundary stock without considering a global scarcity. The absence of discussion about absolute depletion demonstrates a limitation for Game theory: the game is either zero-sum or an unlimited game, in which it is possible to increase the whole rewards. However, this thesis argues that this assumption is flawed, as the present condition of the world is not represented by it. Considering the data as presented in preceding chapters, one can see that the remaining resources of the world at the moment are depleting. Therefore, as the remaining resources of the world shrink through extraction and being used, the situation is altered so that they do not guarantee any economic development for the future of the world. In fact, countries currently work under an economic system where companies can achieve more

resources by outbidding other companies for acquiring such resources. In other words, the most affluent will acquire the resources, which does not lead to sustainability – but rather to conflict (Klare, 2001; Escobar, 2006).

It is essential for sustainability to make the optimum use of depleting resources; therefore, new calculations are needed. This game is neither zero-sum nor non-zero sum with the assumption that the overall outcome would be increased. Therefore, there is a need to develop new calculations. If the game is to show the reality of the world and access to resources, then it should be a non-zero one in which, the overall amount of resources is reducing. It is an extension to Game theory that demands another strategy. Through this it can be shown that collaboration is the best way to achieve optimum outcome. Therefore, in order to ensure sustainability and sustainable development – instead of competition – another strategy as collaboration is needed, as the former will not be effective any more. As Marshall McLuhan stated[78]: "Our Age of Anxiety is, in great part, the result of trying to do today's jobs with yesterday's tools".

As previously discussed[79], it is often the case that when cooperation takes place, the benefits can increase and be shared among the parties involved, and the analysis has shown this. The sharing of these benefits has been often discussed in the context of the Shapley value (Shapley, 1953) and focusing on utility maximisation (Gul, 1989) or upon cooperation (Faigle & Kern, 1992). Alternatively, the Nash cooperative bargaining solution (Nash, 1950) has also been shown as relying on cooperation (Okada, 2010) and shown by Britz, Herings & Predtetchinski (2010) to break down without that cooperation. The various discussions and pitfalls make it seem essential that some form of regulation is needed in order to achieve any solution which would be sustainable.

The significant feature of the Prisoners' Dilemma is that each firm, acting alone, will seek to maximise their benefits through competition. Indeed, the economic system upon which all markets are based expects competition. Furthermore, collaboration – which exists from time to time in the form of cartels – is generally specifically prohibited. However, from a global perspective, the collaborative approach produces the best result, and the preference becomes

[78] https://www.brainyquote.com/quotes/quotes/m/marshallmc400205.html accessed 24/5/2017
[79] Section 2.18

even more pronounced in the era of diminishing resources. This result will never be chosen without some kind of external intervention, labelled here as regulation; other forms of external intervention (e.g. forced compliance) would work equally well.

Therefore, this presents a dilemma, because the benefits – for individual firms and for the whole world – require different approaches. Firms are presently not allowed to collaborate, and countries have a poor record for global collaboration. This is exacerbated in the present situation, as the bulk of the resources in demand and of limited supply seem to be located in countries which are developing, whereas the economic activity is more likely to be located in countries which are fully developed but poor in resource availability. Dealing with this dilemma is the topic for this chapter.

6.5 Regulation and the organisation of international trading

The argument and the data show that cooperation is preferable to competition in optimising the distribution of mineral resources extracted. This poses the dilemma outlined above concerning the conflict between global needs and the needs of individual companies or countries. This dilemma needs to be resolved, and can only be resolved by the consideration of the needs for sustainability for the world. Sustainability needs equity (Klugman, 2013) – not just between different parts of the world, but also taking into account the future in terms of intergeneration equity (Okere, 2006). Some mechanism to achieve this is needed (Meynan & Doornbos, 2004), which needs to be considered in terms of utility (Gowdy, 2005). Utility, in this context, means utility of the use of available minerals.

The economic model currently used for resource acquisition – and indeed for all other forms of trading – is based upon the market as a mediating mechanism. The dominant ideology of the operation of the market is based upon free trade, with the implicit assumption that complete freedom will ensure the best possible outcome (Hurtado, 2008). This is underpinned by the Utilitarian philosophy of Bentham (1834), which assumes that maximizing individual utilities is the way to maximize total utility. Although the concept of the tragedy of the commons had been described by Lloyd (1833), it has not been named as a concept until Hardin did so in 1968 (Hardin, 1968), and so its refutation of Utilitarianism was not recognized in Bentham's time.

Since the recognition of the tragedy of the commons, the approach taken throughout the world has been to mitigate its effects through the privatization of ownership rights (e.g. Smith, 1981). Some (e.g. Skyner, 2001) have even argued that the regulation of the commons is in breach of

the Universal Declaration of Human Rights: article 17 states that “no one shall be arbitrarily deprived of his property”, and regulation would have this effect. So, the free market system continues to reign supreme. Currently, even the governments which have actively fostered the free market system recognize that it is not perfect, and have some monitoring and regulatory oversight attached to its operation. The system is based upon the concept of perfect competition, which is taught in introductory economics (e.g. Lipsey & Chrystal, 2015), but rejected thereafter. It is based upon the assumptions that there are sufficient buyers and sellers, so that none of them is large enough to influence the market. In reality, the number of sellers is small and continues to become smaller through mergers and acquisitions, until the few sellers have a great power imbalance in their favour when compared to the large number of buyers. Power imbalances prevent the working of the free market (Makowski & Ostroy, 2001), and indeed led to some of the problems in the global failure of 2008 (Helleiner, 2011). They also show the fallacy of Utilitarian economics, as overall benefit by summation does not represent the best possible outcome (Postema, 2006). However, as Roberts (2011) argues succinctly, some regulation is deemed necessary with any form of social contract resulting in common activity. Even when the British government under the leadership of Thatcher began the course of privatization – in the belief that the free market was the route to economic efficiency – they were swayed by the arguments of Veljanovski (1988; 1991) that regulatory oversight was essential (Thatcher, 1998). Therefore, the case for regulatory oversight of markets seems to be overwhelmingly accepted, although some still argue for its minimisation.

Within a country, regulation is a relatively straightforward affair: it just requires the government to insist upon this, and to establish a body to undertake the regulatory monitoring. The laissez-faire approach has been to allow industries to regulate themselves, and this is still common practice in the UK (Bartle & Vass, 2005). Often this has proved unsatisfactory, and increasingly, the government has become involved in the establishment of regulatory bodies and imposing external regulation (Kaye, 2006). As this happens, of course, the burden of regulatory costs falls upon companies, and resources must be devoted to their satisfaction. This thesis shows that this still is outweighed by the benefits of a collaborative approach to the management of resources acquisition.

The collaborative approach means that markets cannot operate independently based upon supply and demand, with price as a mediating mechanism. Some form of regulation is needed to provide the necessary governance of these markets. This, of course, poses a problem. It is

relatively straightforward for national governments to impose regulatory oversight over the activity within their borders. On the other hand, manufacturing production is increasingly a global business with resources being acquired from one country, used in manufacturing in other countries, and then sold in multiple countries. This requires regulation on a global basis and some form of global governance of markets.

6.6 Global regulatory bodies

Global regulation requires global organisations to exist with the power of sanction for non-compliance. This, in turn, requires national governments to surrender some of their sovereignty to these bodies. And this is problematic; even the surrender by the UK of some of its sovereignty to the European Union has been so difficult that currently the British people have voted to leave the EU, with one of the arguments being about sovereignty (Gordon, 2016; Ewing, 2017). At a global level, this would require the agreement of all nations. Currently, there are 195 nations, a number which is almost double that of 60 years ago. Some are significantly more powerful – and therefore more influential – than others, but reaching global agreement is a very difficult process and almost impossible. Even the major countries of USA, Russia, China and the EU (with possibly the UK added) cannot agree about very much. Also, the 27 countries of the European Union have difficulty in agreeing about many things (Tallberg, 2004).

However, there are a number of global bodies which manage to exist in some kind of satisfactory way. The principle one is the United Nations, which has a number of subsidiary organisations within it. The main ones are the General Assembly, the Security Council, the Economic and Social Council, the Trusteeship Council and the International Court of Justice. Regulation of international trading does not fall within its ambit. For this, the World Trade Organisation exists. It started in 1995 to replace the former GATT[80]. This merely forms a basis for extensive discussion surrounding the reduction of taxes for international trading, but has made slow progress, because it still needs the agreement of all countries before acceptance. For example, the Doha Development Round commenced in 2001 and collapsed in 2011. Currently, the Paris Accord (the most recent version of the agreement) is uncertain after the US

[80] General Agreement on Trade and Tariffs

withdrawal, despite evidence (Jackson & Grinstead, 2018) supporting its prediction of such global consequences as sea level rise.

However, there are a number of successfully operating global regulation systems. A prime example would be the Basel III concerning the international regulation of banking (King & Tarbert, 2011). Another would be the operation of the international legal system (Krisch & Kingbury, 2006), which is based upon a consent model of regulation, although supported by a strong enforcement mechanism for non-compliance. Another system which has been in existence for almost a century is that of the regulation of whaling; although this has been criticised many times (Suhre, 2000), it has remained largely effective, again primarily based upon international consent.

Therefore, it is reasonable to say that a global body – in a position to establish and monitor a collaborative approach to the functioning of markets in the distribution of resources – does not exist. If the need is accepted for a change in the market mechanism – as this thesis would recommend – then there would be a need for the establishment of a body to undertake this. This would be necessary, but would certainly not be an easy process: global benefit is in conflict with national as well as corporate self-interest.

However, it is important to remember the argument of Popper (1957) regarding the poverty of historicism. In this argument, he contends that an analysis of the past is no guide to the future, and that basing any expectations upon what has happened in the past is flawed and unreasonable. Thus, the fact that solutions have always been found previously gives us no cause for either optimism or pessimism in the present and immediate future.

6.7 The need for regulation

All organisations need some form of governance (Bevir, 2013). At its simplest, governance is merely a set of rules which define the way the individual members of an organisation interact with each other. It is only when the term is used in either a political sense (when it has other connotations), or in a corporate sense (when it refers to relations between the corporation and its investors), that it has a particular meaning. In general, it applies to any organisation of two people or more who need some sort of rules to engage in mutual activity (Jackson et al., 2008). Thus, the markets which exist for raw materials trading need some form of governance

(Williamson, 1979) when adapted to a collaborative approach. The whole purpose of governance rules is to share procedures to enable the organisation to function; this is, of course, based on the principles of transparency, fairness, accountability and the rule of law.

It seems that the United Nations does not fulfil the role of world governance, although some (e.g. Bull, Boas & McNeill, 2004) consider it as a possibility, and perhaps, desirable. Indeed, the pressure group Forum for a New World Governance[81] exists to promote this concept. Thakur and Vangenhove (2006) carry this concept forwards further by proposing regional governance bodies, which eventually will become global governance. However, such writers seem to fail to differentiate between governance, as a governmental function, and governance, as simple rules of operation. Thus, governance has become inseparable from the political domain, and it is here where any proposal will fail, as nations are reluctant to surrender their autonomy and sovereignty. However, without these rules, international relations are subject to the uncertain fluctuations of political alliances, and to the use of power, with the most powerful nations exerting the greatest influence. Those examples of international governance, which are operating successfully, are always based upon the consent model. Thus, the consent model seems to be confirmed by actual practice, although the argument has been made that this also needs strong enforcement.

However, governance of global trading markets implies no political content: it is merely rules of process and dispute resolution, which are nowhere near as controversial. To an extent, this already exists in the form of international trading – via the WTO rules, which act as a default if no alternative between countries has been agreed (Isaac & Kerr, 2003). This is especially so for international finance (Quinn, 1987). In each case, the regulation is not separated from the political domain – which can cause problems in both monitoring and enforcing sanctions, and even in agreeing change. As the existing forms of regulation are of competitive economic markets, then it is indeed difficult to separate the regulation of it from the use of power, and therefore, from the political domain. This is probably one of the major causes of the difficulties which arise in the negotiation of trading regulations. Therefore, it is helpful to consider both the purpose of regulation and the new environment suggested by this thesis.

[81] http://www.world-governance.org/spip.php?rubrique6&lang=en accessed 14/3/2107

6.8 Governance and regulation

The rules of governance need to be written so that they are available to everyone concerned, and it can thus be seen that everyone is following the same procedures or would take the same actions in the same circumstances (Sama & Shoaf, 2005). If the rules of governance are incomplete or are not fully written down, then this can lead to corrupt activity or the misuse of power. This is true of any form of organisation and is not limited to commercial organisations or to governments. An example of this is FIFA and the Sepp Blatter era, where poor governance[82] was held responsible to the corruption problems experienced. From this, it follows that transparency must exist, so that concerned parties can see that all others are behaving in the agreed upon manner. Therefore, this requires accountability, so that people can be held responsible for actions taken or not taken. With accountability comes the need for regulation (Braithwaite, Coglianese & Levi-Faur, 2007), and therefore, this requires some form of regulatory oversight.

Regulatory oversight necessitates someone to undertake this function (Boo & Sharma, 2008), and this can be done either internally – by the organisation itself – or externally – by either an existing body or one set up expressly for this purpose. The accounting profession provides a prime example of an internally regulated organisation (Johnston & Pelacchi, 2017), while the Enron scandal (Toffler, 2003) provides a prime example of the problems that can ensue from this form of regulation. An example of external regulation by an already existing organisation is given by the WTO and trade regulation, which is expressly established for the purpose. Another is given in the UK by the Financial Services Authority, which has since become two bodies: The Financial Conduct Authority and the Prudential Regulation Authority, controlled by the Bank of England. As argued above, regulation within a country is not a great problem, as it can be imposed by the government, if all else fails. However, markets for the trading of raw materials are a different matter, as this trading is done in an international manner in global markets. Indeed, the market as such is often virtual, as the price mechanism works in any competitive environment. Effectively therefore, this is a global market which would require regulating on a global basis. Additionally, it would require establishment of a regulatory body

[82] https://www.theguardian.com/football/blog/2015/jun/09/fifa-reform-manifesto-football-sepp-blatter accessed 14/3/2017

to provide this oversight, and with the power to impose the sanctions agreed upon in the event of non-compliance (Kershaw, 2005).

It is difficult to see how this process could be established without the agreement of all nations, and certainly, the agreement of the most powerful nations. The evidence cited above suggests that regulation works best with consent. It is equally difficult to see how this could be established without any geopolitical considerations. It should also be recognised that, at the moment, the power lies mainly with the consuming countries of those raw materials, as they have the economic resources and extract greater value added from the employment of resources in production. However, as time progresses, the scarcity of resources – as they become more deplete – will increase, and this will inevitably change the power basis towards those who have the raw materials and away from those that desire them. Conceivably therefore, Marshall McLuhan's prediction (McLuhan & Fiore, 1968) – that future wars will be based on economic criteria – has been shown to be both prescient and in need of serious consideration. Dubrinski (2013) has noted that the BRIC countries possess a considerable share of these remaining resources, while also developing their industrial capability. This will have a significant effect on the current markets for resources, and will become more pronounced as time progresses. So too will resource depletion and the development of industrial production capability in these (and other) countries (Nayyar, 2016). This, of course, would strengthen the argument for a collaborative approach – at least among the developed but resource poor countries (such as the UK) – but would perhaps lessen the desirability among developing but resource-rich countries. This also increases the likelihood of armed conflicts increasing. Such conflicts exist at the present and have been forecast for the future (e.g. Theisen, 2008; Koubi et al., 2014), as well as in the past (e.g. the invasion of Iraq in 2003 Bassil, 2012).

The regulation of the market for raw materials in a collaborative environment would require the establishment of a new organisation with a new set of rules (Hallack & Vazquez, 2013). Of course, this is possible, and an example is the Russian federation after the collapse of the USSR. An example of how this can be done is given by de Rosa (2008), who argues that this needs to be done by first establishing a regulatory oversight body to oversee reforms and their quality, followed by strengthening the capacity of competition and network authorities. Therefore, it is possible but experience shows it to be a lengthy process. Of course, it is more complex for the world, as there is not an overarching body who can determine these features and instead, consensus must be sought. One of the basic principles of such a market for minerals would

have to be the allocation of resources. The conventional mechanism for market exchange is that of price. This would not work in this situation, as price allocates resources to those who can pay the most, and therefore, probably in developed countries; in this situation resources would need to be allocated to enable the greatest use to be made of them (De Figueiredo & De Figueiredo, 2002). This raises several problems:

- Determining optimal use

In theory, the best use of any resource can be made by those who will pay the highest price. In other words, the pricing mechanism automatically ensures an optimum allocation of resources. However, it has been argued here that this no longer applies when supplies are restricted and cannot be increased, as with mineral resources. In this case, pricing might allocate according to economic ability, but this differs from utility. There is a need for some mineral by all, regardless of price or ability to pay. Thus, for example, copper is a trace element needed by everyone for actual existence, regardless of price. Other minerals are needed for a variety of reasons; thus, optimum allocation of a scarce resource is best undertaken according to need, in order to ensure equity and sustainability.

At the moment, use is determined by what is most profitable to the party purchasing, which may well not be what is best for the world as a whole. According to economists (e.g. Calsamiglia, 1977) determining the best use will not work satisfactorily without price as the mediator. This also presupposes a short-term view of what is best, whereas a sustainable future might need different decisions when the future is taken into account – in other words, the long-term view might well need to outweigh the short-term view and immediate profitability. A further difficulty is that optimal use is not an absolute concept, and alternative uses may well be preferred by different people

- National prejudices

National interests and prejudices cannot be separated from a global allocation process (Francis et al., 2009). Many countries have preferred trading partners, such as the claimed special relationship between the UK and the USA, or the reinstated special relationship with commonwealth countries. Equally, many countries are wary of trading with certain others due

to such reasons as ideological reasons or religious differences or preferences for these reasons. It could be claimed that economic utility ignores such preferences and prejudices (Bettis & Prahalad, 1983. However, in reality, the trading of increasingly scarce resources can never be separated from either political influences or from power relationships.

- Intergenerational equity

When resources are fixed in quantity – as are global mineral resources – then it is axiomatic that what is used in the present is not available for future use. Equally, sustainability requires the leaving of available choices to future generations. This raises the question of intergenerational resource availability (Padilla, 2002). Therefore, optimal resource allocation must take this into account (Howarth, 1991), which is problematic both for present use and for anticipating future requirements.

- Political influences

Political processes among nations consider a wide variety of aims and objectives which are not economic. Indeed, strategic objectives are often more important, and these could outweigh economic benefit in decision-making (Zhuang & Bier, 2010). Thus, the optimal sustainable capability of the world as a whole is almost never considered, and does not even rank on most decision-making processes in the political arena. Indeed, even if war is engaged in for economic reasons, then the outcome might be beneficial for some individual countries, but is never beneficial for the planet as a whole: some nations become worse off as a result. It is also the case that resources are used for one purpose, and therefore, diverted from other purposes; the net productive capacity of the planet is reduced in this manner. As resources become scarcer this becomes an increasingly important consideration. However, Wang, Luo & Gai (2017) show that Game theory can deal with this uncertainty in matters of national security. Although they do not consider the effect upon the world as a whole.

- Corruption

Regulation is part of governance, and human nature means that procedures become more lax as they continue in existence. Rules get ignored, and corruption creeps into the system (Shleifer

& Vishny, 1993). With most systems of governance, this can be overcome by an oversight of the process – regulating the regulators. At a national level, this is not really a problem, as there is always a higher authority (Builte & Damania, 2008). However, at a global level, such as required by the global market for minerals, there is no higher authority who can check on the world governance of markets.

6.9 Resource allocation

It is apparent that there are considerable problems with trying to operate a means of resource allocation based upon collaboration and the agreement of the world. However, this research has shown that this is the optimum method to allocate the remaining mineral resources of the world. Indeed, any alternatives would tend towards an unsustainable outcome in the longer term. However, in order for this new market to work, there will need to be a method of resource allocation, having recognised that price does not act as an efficient medium of exchange. There must, therefore, be a method of recognising (and accounting for) an exchange of value, with the purchaser receiving the raw materials and the seller receiving a reward instead. The only available mechanism for this is money, and this works very well as a means of recording value. It is just the price setting mechanism which needs to be adjusted from being based on scarcity to being based on utility. The only way this has been done without price setting through the market was in Soviet Russia, where resources were just allocated centrally. This was generally recognised as unsuccessful (Treisman, 1996), in part because it was impossible to separate benefit (i.e. utility) to the people as a whole from governmental political desires. Various technical suggestions have been made by various people (e.g. Fair & Jaffee, 1972) for ways to set price in situations where supply and demand do not operate satisfactorily, but without suggesting methods of implementation. There are also many examples where governments have intervened in the market, but this has been chiefly to alter price for the benefit of individual consumers; or simply as a revenue raising mechanism – such as for petrol or alcohol; or to affect demand for goods – such as tobacco for health reasons. Indeed, regulation and manipulation of price has been a constant feature of the imperfect markets, created by the privatisation process. This has been described (Crowther, Cooper and Carter, 2001a; 2001b) as a ritualistic process without real meaning, but aimed to satisfy popular opinion.

It is clear that some mechanism for exchange is needed, and that price in monetary terms works efficiently throughout the economy. Intervention to affect price for the overall benefit of a

sustainable world is necessary, as this has been shown to be desirable. It is here where difficulties arise, and no satisfactory solution has been seen to exist. It is difficult to arrange for satisfactory regulatory oversight to achieve this – because of political factors and a lack of any global supranational organisation to effect this. This might be taken to imply the need for global politics to become supreme, and for a global governmental organisation to be created, subordinating national governments and interests. This is unlikely to happen in the near future, and its creation may not be strictly necessary if any alternative can be found, based presumably upon the consent model of regulation. However, having said this, the governments of the nations of the world have managed to combine together to take action, when they agree that it is really necessary. Thus, the United Nations was established in the post-war settlement of 1945 by 50 countries[83], but has since been accepted by all 193 countries of the world. Similarly, climate change has been recognised as being a real phenomenon, and the Climate Change Convention came into force in 1994; it has since been recognised by almost all countries. Thus, there is evidence that a global problem can ultimately be solved, and therefore, there are grounds for optimism, although any solution is outside the scope of this thesis. Equally, there is evidence that such structures can be established and made to operate.

6.10 Chapter summary

The most significant implication of the results of the analysis from this thesis is that collaborative market exchange is necessary but problematic for a number of reasons. While there are models which exist to show that such a method of distribution can be implemented and regulated, there are a number of problems in establishing the necessary regulatory oversight. The problems seem to resolve into manipulation of the pricing mechanism to govern both exchange and diverting supply and demand away from profitability towards utility. Furthermore, the determining of optimum utility is also problematic. There are a number of implications from this analysis, which are discussed further in the final, chapter.

[83] http://www.un.org/en/sections/history/history-united-nations/ accessed 14/3/2017

Chapter 7

Conclusions to Research

7.1 Introduction

In this chapter, all the points in previous chapters are brought together to summarise the research. Here, the findings of last chapters are highlighted, and their implications are discussed. The research objectives are revisited, and it is pointed out how these objectives have been observed. Other matters considered in this chapter include areas for future research and contribution to knowledge.

7.2 Research summary

Our planet is heading towards a new era. In this new era, it needs now to address the effects of climate change. At the same time, the effects of depletion of minerals are starting to be realised and extinction periods are being considered, although with no certainty. Accordingly, society needs to deal with some problems as they become more urgent. As an example, managing in a world after Hubbert's Peak means that it is important to utilise energy with the highest efficiency possible. On the other hand, continuous economic growth with the limited amount of resources reveals the consequences of depletion of resources even more.

Therefore, it is important that the decisions made would lead to the best usage of the shrinking resources, and this should be encouraged by the governments. If manufacturing is performed with efficiency, as a result, the manufacturing costs will be kept at minimum – which is an important point for sustainable development. Dealing with this issue needs to consider use of raw materials and procurement in a different way and based upon a different level of their availability. Moreover, there is a need to consider the implications in terms of access to resources to the whole world; any perceived inequity could lead to conflict and would be unsustainable. This has to be dealt with in terms of who to distribute the available minerals to in different levels of nations and companies.

Thus, accordingly, the problem statement was defined as follows:

Resource depletion is manifest in many ways, but principally, concerning the extraction of minerals and energy production and consumption. Economic activity in this new environment needs to be defined and explained, and Game theory provides a mechanism in this thesis for doing so.

7.3 Revisiting aims and objectives

This research has been aimed at understanding the current situation in which availability of mineral resources – which are finite and depleted – has made them constrained, and also at developing strategies for managing distribution of those increasingly scarce minerals through the markets in this environment. The problems arising from this new environment and its management are also considered. Accordingly, the research has been focused on different levels of companies and market in general; thus, analysis is obviously made through different methods while the applied mathematics resolves this correctly.

The aims of this thesis have been described as:

- To identify and describe this new environment
- To understand the optimum operation of the market in such an environment
- To consider the problems arising therefrom.

The thesis has shown that we are now entering an environment of resource depletion, in which the extractive minerals are becoming scarce in availability due to the finite amount of each available on the planet. As discussed in chapter 2, the exact scarcity is in dispute, as is the date of projected exhaustion. However, it is clear that what is extracted in the present will not be available for the future, and the effects of scarcity will be felt during this century for many minerals. In such an environment, the requirement must be to make optimum use of what is available, and this must be addressed in global terms. Equally in this environment, the solution is not to extract more quickly, nor to base distribution solely on price. Thus, the market must change so that distribution is based upon utility of need rather than ability to pay. This is the only way to avoid conflict and achieve sustainability. On this basis, therefore, it has been argued that a collaborative approach to distribution is more effective than a competitive one.

This shows that a new market environment must be created based upon global need. To establish this requires some interventions into the market, and this has been described here as regulation. There are obvious problems in instituting such a regime for the market for the various minerals which are becoming scarce, and these have been considered in chapter 6. So too have the various examples of ways in which such global regulation has been attempted in other spheres. In these ways, the aims of the thesis have been addressed and achieved.

Further to this, the objectives were described as below:

1. To consider and define the requisite mineral extraction in this new environment, and to consider the implications for sustainability.
2. To consider the alternative methods of distribution (labelled competition and cooperation in this thesis) of those minerals, and the effect upon recipients.
3. To develop the necessary extension to Game theory which will deal with resource depletion, and to perform the necessary theoretical developments for this environment.
4. To apply the resulting formulae in the empirical calculation of the effects of resource depletion.
5. To identify and consider the requirements for governance in the management of the new distribution environment and the implications of this.

By applying mathematics, the abovementioned objectives have been theoretically addressed. The mathematics used for this purpose has primarily been Game theory; in order to do this, it was required to develop four new extensions: Resources' paradox, Reducing sum game, Gaia Game extension, and Application of a mathematical approach to an economist situation. Thus, the current thesis has resulted in developing Game theory even more to enable understanding of the current situation of the world. The first objective was achieved by describing previous research and the relevant alternatives considered therein. Objectives 2 and 3 have been addressed by the developments to Game theory.

Applying a different strategy is needed for managing in the current environment. It was shown through Prisoners' Dilemma scenario that (except in short run) for any firm and also for the economy of the whole world it is better to collaborate than to compete. Thus, the second objective was achieved through the mathematical calculations developed. Then, the resultant mathematical formulae were applied to actual data of different industries and firms within those

industries to show that they hold true with actual data. Sensitivity analysis confirmed that the results would hold true through all reasonably possible values of actual data. Thus, the third objective was achieved by this discussion and ensuing calculation. It was shown by analysis through Game theory which was also supported through linear programming for confirming the results. Moreover, the robustness of results was confirmed through sensitivity analysis. Then, actual data were analysed for triangulating, which demonstrated their being robust. Thus, the fourth objective was achieved by the application of the model to actual data and the double triangulation of the ensuing calculations.

As a result, the model was refined to show that collaboration brings about a more sustainable distribution than does competition. When applied to this new environment – where price no longer mediates between demand and supply in a conventional manner – the results have implications for sustainability and have a significant impact upon the distribution and access to raw materials. This seems to require some radical rethinking within the exchange markets for raw materials. There are great policy implications as well as implications on the geopolitical front, but these are outside the scope of this thesis. In this thesis, the implications regarding the governance and regulation of these markets are considered, and the final objective is achieved through the recognition of the problems and the consideration of their resolution.

The objectives of this thesis are addressed by means of first addressing some questions of the research:

1. Does resource depletion have an impact upon the way firms acquire the resources for their production, and if so, then how?

Obviously, companies' practice of acquiring resources is affected by depletion of resources; as these resources become scarcer, then they will be more difficult to acquire. This may provide motivation towards technological developments in the products manufactured to enable less of a mineral to be needed or to find alternatives. This is because companies need to be in increasing competition in order to gain the available resources. This is how to deal with resource depletion in terms of supply and demand – although supply will be less, and demand will be higher, even though no more is available. Thus, obviously, the way companies gain raw materials is impacted by shrinkage of resources. Moreover, it impacts on production; companies would desire to use attainable resources more effectively, which has implications

on how to produce and design the products. The unequal distribution of the available resources suggests more implications for the countries and the world economy, but this thesis does not consider geopolitical matters.

2. What changes are needed to address the issue of depletion for sustainability in the global market?

Sustainability requires perceived equity in the distribution of the resources of the world, and as mineral resources become scarcer, then this perceived equity becomes more important. Absence of perceived equity leads to conflict over available resources. It has been argued that for effective operation of markets in the world economy, a collaborative approach is necessary. Therefore, a regulatory mediation is required, not just for the world economy, but for single companies also. This, of course, requires regulatory intervention in matters at a global level when there is not really any suitable body to either determine the regulation or to monitor its application and apply sanctions as necessary. Nevertheless, regulation is needed to make sure that countries and firms collaborate for everyone's benefit, and this research considers the implications of this need.

3. Would a new approach to the global management of distribution of planetary resources be beneficial?

When the needs of sustainability – in terms of equity and long-term perspective at a global level – are accepted, then it becomes apparent that a different approach is needed. By the mathematical calculations in this thesis, it is possible to support this argument, and show the efficiency of using another approach for all concerned. It has been argued that the need for sustainability means that use of mineral resources should be optimised at a global level. Choices must be made by states and by firms to achieve this: either a competitive approach may be taken or a collaborative approach. Collaboration in use of the reduced amounts of available resources is shown to be the optimum approach for the future and the best option for ensuring sustainability in the economic aspects of the problem. Achieving this has been shown to need some changes in the economic management of the resources of the world, and its implications have been analysed.

4. What kind of interventions, if any, are needed for effective management of the resources of the planet?

Here is where resources' paradox matters. The global economy manages through resolving this complexity. There is always a simultaneous wish to compete or to collaborate because of different reasons. Moreover, immediate benefit through the use of the limited resources can often be in conflict with the achievement of long-term objectives, which are necessary in order to achieve sustainability: sustainability must focus upon the future as well as the present. It is also a fact that the economic system of the world is predicated in competition, whereas the research shows that the optimum use of raw materials is achieved through cooperation in their supply, distribution and use. This would seem to require some kind of intervention in the markets for extractive raw minerals.
Thus, it can be observed that the set objectives of the thesis have been met, and that also the set questions of the thesis have been responded as well. Accordingly, this thesis has succeeded in doing this, although several limitations exist which will be considered in the following section.

7.4 Research limitations

The focus of this thesis is about the distribution of mineral resources, and the argument made has been that the amount of such resources is fixed, and by the growth of the global economy, their supply has become scarce. Although it is obviously true – as calculations have been performed on the basis of this assumption – it can be considered as a limitation; it is always possible that unlimited supply of these materials may be discovered, or the resources of another planet or comet become available for use. However, for all practical purposes, this possibility can be discounted and ignored within any pertinent timescale.

The basis of the world economy is competition, and when raw materials are getting scarcer in comparison to demand, competing for the remaining resources becomes harder. In performing the calculations, it is assumed that it is possible to use a sort of market regulation for facilitating cooperation instead of competition. But it has not ever occurred in the economic system of the world, and introducing and operating of it might actually cause problems. Thus, it can be considered as a research limitation. Political factors may also intervene with economic scarcity, leading to armed conflict as suggested by McLuhan (McLuhan & Fiore, 1968) and Bulloch &

Darwish (1993). Anyhow, evidence suggests that as the situation requires it, then it is possible to achieve a kind of global regulation. As an instance, it is possible to mention the world system for trading carbon emissions, while another could be considered to be the World Trade Organisation (WTO). Indeed, the United Nations, itself, can be regarded as a reasonably successful example. Liverman (2008) criticises carbon emission accounting as being a kind of colonialism in which prosperous countries are able to keep their consumption levels by acquiring credit of saving carbon emissions in projects without efficiency. Another instance to be mentioned is the Tobin tax (Tobin, 1978) as a mechanism for controlling international currency flows and their detrimental effect upon certain economies. So, there are examples for this kind of regulation and the efficacy of it; however, one can consider it as a thesis limitation.

The robustness of calculations has been demonstrated. Some assumptions have been made which can be a limitation to the thesis. It is possible that using more data from different firms or different industries would affect the analysis. It is also possible that the after effects of the current global viral pandemic will affect the argument significantly; it is of course too early to comment on this. Apart from this, the whole analysis and the results of it hold together.

The analysis has been undertaken through a mathematical analysis and a richer understanding would be obtained if some qualitative data of the various actors was collected and analysed. Possibly also a consideration of the geopolitical issues would enhance understanding, certainly with respect to implementation.

7.5 Contributions to knowledge

In this research, the primary questions have been examined completely and answered properly. For this purpose, the analysis has been initially done using mathematics, mainly by application of Game theory followed by linear programming. For this, four extensions have been added to Game theory; this thesis has mainly contributed to knowledge by means of extension of Game theory to the modern circumstances, and by means of development of the extensions created. Previous research has only made proposals to deal with this, but never actually developed and tested any model; therefore, this model itself is a contribution. Thus, the thesis can be considered to add knowledge by the detailed consideration of the remaining mineral resources, their impending scarcity and the implications for global sustainability. It can equally be considered as deepening our knowledge regarding future sustainability and the effect of

mineral scarcity and the implications thereof. It, also, deepens knowledge through addressing the global distribution of the remaining resources and ways to address this issue. As such, it is concerned with the future as much as with the present.

Furthermore, this thesis contributes by applying the extensions developed to the world practice, and by considering the part that regulation can play effectively in global – rather than regional – resource market management. This is basically done via comprehending the dichotomy of cooperation and competition, and the argument of the thesis is on solving the problem of the conventional economic system that emphasises on competition – instead of cooperation – to achieve sustainability of resources.

Thus, the contribution made by this thesis can be described as follows:

- theoretical contribution: the thesis has developed theory to show that Game theory can be applied in this environment in order to consider global sustainability. In doing so it has developed four extensions and demonstrated their relevance. It has developed the theory and shown its robustness.
- empirical contribution: this thesis has shown that the theory developed is robust through its applications in real world situations. Therefore, it has shown how the theory can be applied in practice.
- methodological contribution: the method of applying Game theory in this manner has been shown to be methodologically sound in its application and relevant to the problem of sustainability at a global level.
- practical contribution: the thesis has shown the policy issues involved in achieving sustainability in the distribution of depleted minerals, and has shown how this methodology can be used to contribute towards that sustainability. This is true in the present, and even more so in the future, as the scarcity of remaining resources becomes more apparent.

7.6 Generalisability

It should always be possible to generalise the findings of any research further than the present topic, and this is important for showing the contribution of the research. Replicability, as a

feature of generalisability, means how far it is possible to verify the research findings through similar and further research. Replicability was demonstrated to be completely possible and yielding identical results through application of sensitivity analysis, as well as through the calculations in chapters 4 and 5. It means that the identical results will be achieved by use of any relevant data that has been collected for this research. The model provided by this research demonstrates what is the optimum behaviour of organisations in the modern era of depleted resources – where depleted resources are raw materials needed for production. Accordingly, there is a need for different attitudes towards production and strategic decision-making to make best use globally of the reducing resources available. Moreover, there is a need for a kind of mediation for market management, which has been addressed as regulation – or a similarly suitable word, which is governance. The scope of the model is perfectly general and applicable to different markets or industries; hence, generalisability is clear.

7.7 Areas for further research

This is a general research which is first performed theoretically, and afterwards, it is tested through application of real data. The real data has been basically applied to evaluate the regulation costs for raw material markets at global and national levels, and to demonstrate the validity of analysis for different levels of global and industrial. The scope of this research can be extended to greater data sets, and also to investigation of different countries and industries. More work on market regulation on global or national level is also a desirable possibility. It would also be beneficial to test the model through data sets in wider timeframe. Additionally, because there are no other models, work could be undertaken to develop either this model or an alternative.

It is possible to extend the model to incorporate more elements, and therefore, to model all elements inside the system, and to show whether a single point of equilibrium under all circumstances comes with cooperation. It could also be extended into a consideration of the techniques required for collaboration, and of the effects from the integration of resource depletion into industrial engineering processes.

Geopolitical factors are very significant in the consideration of the creation and management of the global markets; this is necessary for the establishment of a market involving

collaboration. Therefore, this thesis could be extended into the development of such a collaborative model and its operation.

7.8 Conclusion

This thesis adds to our knowledge of how the market and companies behave. It also provides a better understanding of performance and decision-making of companies. This is achieved through the following:

- Improved knowledge about the cruciality of resources limitedness and its implication on the operational and strategic decision-making of firms

- Developing another approach to, and improved knowledge on, the decision-making motives at national and company levels regarding optimising the distribution of the available mineral resources

- Creation of knowledge about the necessity of regulation for the world market

Such knowledge has been developed through undertaking the analysis in the thesis, the way the analysis has been interpreted and the development of implications from the analysis. Obviously, it can be claimed that the interpretation can be imprecise – as this is only one interpretation – but the validity is shown through sensitivity analysis. Thus, the significance of the thesis is based upon its interpreting a modern era that is not completely understood. In order to tackle this modern era, the thesis has resulted in four extensions for Game theory.

Accordingly, it provides for more works to be done, which is another reason for its significance. Therefore, the analysis of this thesis stands on its own merits.

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31 October 2017

Dear Shahla

Re: Sustainability in Manufacturing in an Era of Depleted Resources

This letter is to confirm that your research has received ethical approval by Chairs Action on behalf of the College of Business, Research Ethics Committee.

Yours sincerely

[redacted]

Dr Tracey Wond
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Appendix 2

Publications from the thesis

Refereed journal papers:

Using Game theory to develop sustainability strategies in an era of resource depletion; *Industrial Engineering and Management Journal*, 7(1); 2018 DOI 10.4.172/2169-0316 1000250

Book chapters:

Is a Planet B necessary? Arguments concerning depleted resources and consequences for sustainability; in D Crowther & S Seifi (eds), The Components of Sustainable Development: Engagement and Partnership; London & New York; Springer; pp

Game theory; in D Crowther & L Lauesen (eds), *Handbook of Research methods in Corporate Social Responsibility;* Cheltenham; Edward Elgar; 2017; pp111-124

Sustainability and resource depletion; in D Crowther & S Seifi (eds), *Modern Organizational Governance*; 2017; Emerald; Bingley

Conference presentations:

The Game of Thrones: Geopolitics and resource depletion; 18th International Conference on Corporate Social Responsibility; Barcelos, Portugal; Sept 2019

Is a Planet B necessary? Arguments concerning depleted resources and consequences for sustainability; 17th International Conference on Corporate Social Responsibility; Bangalore, India; Sept 2018

Using Game theory to develop sustainability strategies in an era of resource depletion; 16th International Conference on Corporate Social Responsibility; Buxton, UK; August 2017

Using Game theory to develop sustainability strategies in an era of resource depletion; Postgraduate Research Conference; University of Derby UK; May 2017